FINAL REPORT

Demonstration of Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry at Former Camp Beale, California

ESTCP Project MM-0535

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Final Report
Demonstration of Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry at Former Camp Beale, California

Project No. ESTCP-200535

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14. ABSTRACT
Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry (HeliMag) technology was demonstrated as part of the ESTCP Wide Area Assessment Pilot Program. This report documents the acquisition, processing, analysis, and interpretation of Helicopter Multi-sensor Towed Array Detection System Magnetometry data for unexploded ordnance related sites at nearly 5,000 acres at Former Camp Beale, CA. The performance criteria for positioning accuracy, system noise, data density, MEC parameter estimates, and operating parameters (altitude, speed, overlap, production levels) were met except for the production levels which averaged 259 acres per day compared to the objective of 300 acres per day. Results were inconclusive for many of the areas of interest due to the presence of challenging geology at the site. Because of the geologic masking effects on the results, targets were picked manually.

15. SUBJECT TERMS
Helicopter magnetometry, airborne magnetometry, HeliMag, wide area assessment, WAA, low-altitude geophysical surveys; digital geophysical mapping

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ACRONYMS

1D	one dimensional
3D	three dimensional
AGL	Above Ground Level
AFB	Air Force Base
ASR	Archive Search Report
CERCLA	Comprehensive Environmental, Response, Compensation, and Liability Act
CRADA	Cooperative Research and Development Agreement
cm	centimeter(s)
Cs	Cesium
DAS	Data Acquisition System
DGM	Digital Geophysical Mapping
DoD	Department of Defense
DSB	Defense Science Board
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Sites
GDC	Geophysical Data Center
GIS	Geographic Information Systems
GPS	Global Positioning System
HeliMag	Helicopter MTADS Magnetometry (see MTADS)
Hz	hertz
IMU	Inertial Measurement Unit
kts	knots
m	meter(s)
m/s	meters per second
μSec	microsecond
MEC	Munitions and Explosives of Concern
MMRP	Military Munitions Response Program
MTADS	Multi-Sensor Towed Array Detection System
nT	nanotesla
NRL	Naval Research Lab
OB/OD	open burn/open detonation
RMSE	Root Mean Square Error
RTK GPS	Real-time Kinematic Global Positioning System
SKY	Sky Research, Inc.
TMF	Total Magnetic Field
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UXO	Unexploded Ordnance
WAA	Wide Area Assessment

ACKNOWLEDGMENTS

Demonstration of Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry at Former Camp Beale, California documents the acquisition, processing, analysis, and interpretation of Helicopter Multi-sensor Towed Array Detection System Magnetometry data for unexploded ordnance related sites at Former Camp Beale. The work was performed by Sky Research, Inc. of Oregon, with Dr. John Foley serving as Principal Investigator and Mr. David Wright serving as co-Principal Investigator.

Funding for this project was provided by the Environmental Security Technology Certification Program Office. This project offered the opportunity to examine advanced airborne methods as part of the Department of Defense's efforts to evaluate wide area assessment technologies for the efficient characterization and investigation of large Department of Defense sites.

We wish to express our sincere appreciation to Dr. Jeffrey Marqusee, Dr. Anne Andrews, and Ms. Katherine Kaye of the ESTCP Office for providing support and funding for this project.

1. INTRODUCTION

1.1. Background

Munitions and explosives of concern (MEC) contamination is a high priority problem for the Department of Defense (DoD). Recent DoD estimates of MEC contamination across approximately 1,400 DoD sites indicate that 10 million acres are suspected of containing MEC. Because many sites are large in size (greater than 10,000 acres), the investigation and remediation of these sites could cost billions of dollars. However, on many of these sites only a small percentage of the site may in fact contain MEC contamination. Therefore, determining applicable technologies to define the contaminated areas requiring further investigation and munitions response actions could provide significant cost savings. Therefore, the Defense Science Board (DSB) has recommended further investigation and use of Wide Area Assessment (WAA) technologies to address the potential these technologies offer in terms of determining the actual extent of MEC contamination on DoD sites (DSB, 2003).

In response to the DSB Task Force report and recent Congressional interest, the Environmental Security Technology Certification Program (ESTCP) designed a Wide Area Assessment pilot program that consists of demonstrations at multiple sites to validate the application of a number of recently developed and validated technologies as a comprehensive approach to WAA. These demonstrations of WAA technologies include deployment of high airborne sensors, helicopter-borne magnetometry arrays and ground surveys.

This report documents the demonstration of the Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry (HeliMag) technology for WAA of approximately 5,000 acres at the Former Camp Beale demonstration site in northern California, approximately 45 miles north of Sacramento. This demonstration was conducted as part of ESTCP project MM-0535.

HeliMag provides efficient low-altitude digital geophysical mapping (DGM) capabilities for metal detection and feature discrimination at a resolution approaching that of ground survey methods, limited primarily by terrain, vegetation, and structural inhibitions to safe low-altitude flight. The magnetometer data can be analyzed to extract either distributions of magnetic anomalies (which can be further used to locate and bound targets, aim points, and open burn/open detonation (OB/OD) sites), or individual anomaly parameters such as location, depth, and size estimate. The individual parameters can be used in conjunction with target remediation to validate the results of the magnetometer survey.

1.2. Objectives of Demonstration

The purpose of this demonstration was to survey a subset of the WAA demonstration site in areas amenable to low-altitude helicopter surveys. Specific objectives of this demonstration included:

- Identify areas of concentrated munitions, including the known and suspected target areas;
- Bound the target areas;
- Estimate density and distribution of munitions types and sizes;
- Characterize site conditions to support future investigation, prioritization, remediation, and cost estimation tasks.

A determination of success for this demonstration was based on the performance of the system, as described in Section 4.

1.3. Regulatory Drivers

United States Army Corps of Engineers (USACE) is the lead federal agency under the Formerly Used Defense Site (FUDS) program. USACE administers the FUDS Military Munitions Response Program (MMRP) program using DoD investigation/cleanup methods based on the U.S. Environmental Protection Agency (USEPA) Comprehensive Environmental, Response, Compensation, and Liability Act (CERCLA) process.

1.4. Stakeholder/End-User Issues

ESTCP managed the stakeholder issues as part of the pilot program. ESTCP used a process to ensure that the information generated by the high-airborne, helicopter, airborne, ground validation surveys was useful to a broad stakeholder community (e.g., technical project managers and Federal, State, and local governments, as well as other stakeholders).

1.5. Test Site

The Former Camp Beale site encompasses approximately 64,000 acres located in northern California immediately east of Beale Air Force Base, straddling both Yuba and Nevada counties (Figure 1). The site is located approximately 45 miles north of Sacramento and 20 miles east of Marysville, California.

The physiography and known munitions use history of the study area are discussed in some detail in the Archive Search Report (ASR) prepared by the USACE - St. Louis District/Huntsville Division (1993). The site characteristics and historic military use at the Former Camp Beale are described in Section 3.3.

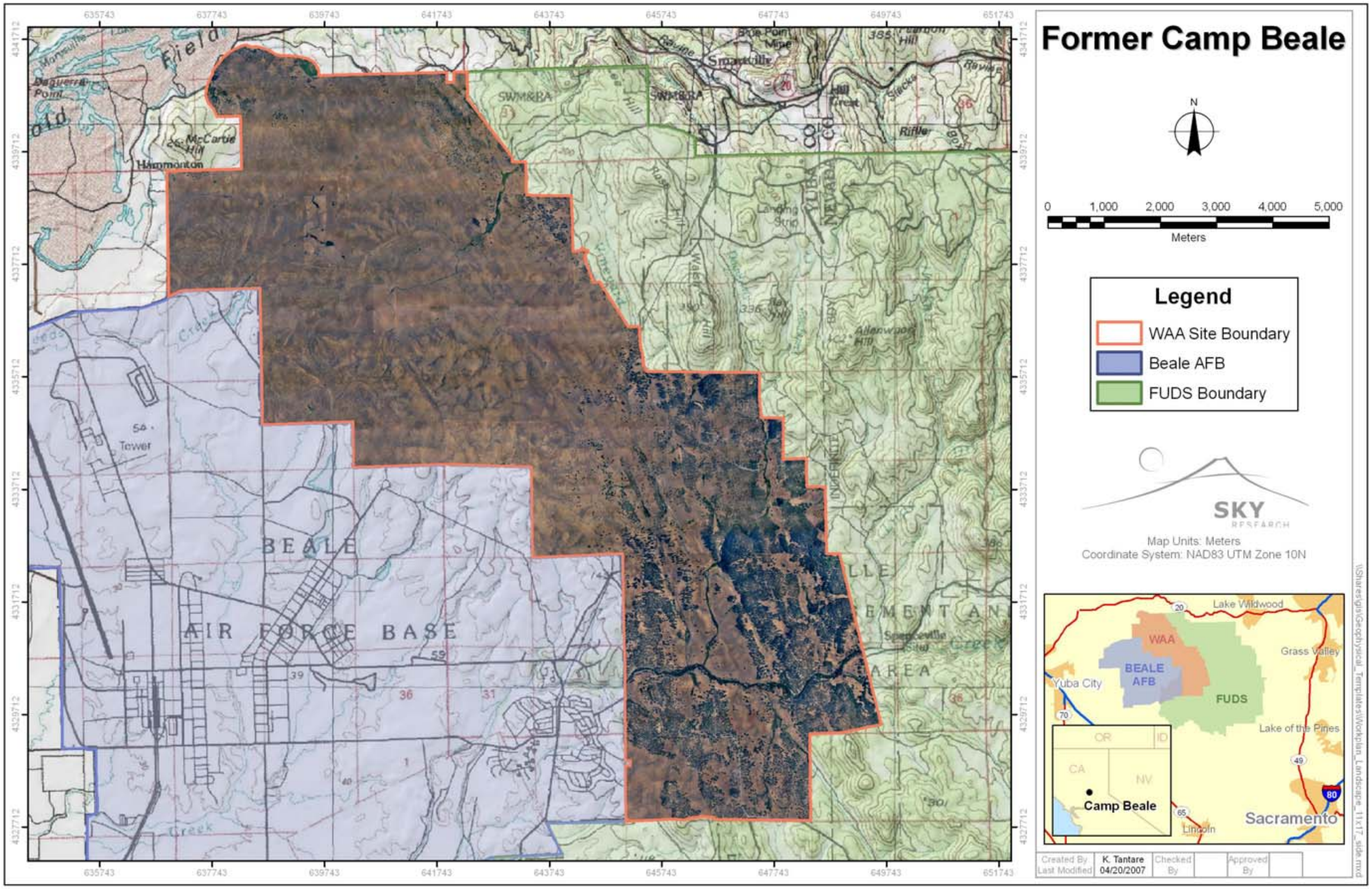


Figure 1. Former Camp Beale and vicinity.

2. TECHNOLOGY DESCRIPTION

2.1. Technology Development and Application

The Sky Research, Inc. (SKY) HeliMag technology is based on the Naval Research Laboratory (NRL) MTADS technology, transferred to SKY for commercialization via a Cooperative Research and Development Agreement (CRADA). Prior to the transfer, this technology was fully evaluated by the DoD by ESTCP (Tuley and Dieguez, 2005).

The HeliMag system includes data collection hardware in the form of a helicopter-borne array of magnetometers and software designed specifically to process data collected with this system and perform physics-based analyses on identified targets. In addition, SKY has recently completed updates to the NRL MTADS technology to improve performance and reliability of the technology. The individual components of this technology are listed in Table 1.

Table 1. SKY HeliMag Components

Technology Component	Specifications
Geophysical Sensors	7 Geometrics 822 Cs vapor magnetometers, 0.001 nanotesla (nT) resolution
GPS Equipment	2 Trimble MS750 GPS receivers, 2-3 centimeter (cm) horizontal precision
Altimeters	1 Optech laser altimeter and 4 acoustic altimeters, 1 cm resolution
Inertial Measurement Unit	Crossbow AH400 , 0.1 degree resolution
Data Acquisition System	SKY Data Acquisition System capable of data collection up to 400 hertz (Hz), 10 microsecond (μSec) timing precision
Aircraft	Bell 206 Long Ranger series or Hughes MD 500 series helicopter

2.2. Helicopter Platform

SKY's HeliMag system can be mounted on a either a Bell 206 Long Ranger helicopter or Hughes MD500 series helicopter. The survey at Former Camp Beale was conducted with an MD500D helicopter provided by Airlift Helicopters based out of Reno, Nevada (Figure 2).

Figure 2. Helicopter and magnetometer boom assembly. Seven magnetometers are contained in the composite-material boom and positioned with the GPS antenna and laser/acoustics altimeters.

2.2.1. Sensors and Booms

The MTADS magnetic sensors are Cesium (Cs) vapor total-field magnetometers (a variant of the Geometrics 822 sensor, designated as the Model 822A). The array of seven sensors is interfaced to a data acquisition system (DAS) and the sensors are evenly spaced at 1.5 meter (m) intervals on a 9 m Kevlar boom mounted on the helicopter. The boom used for this data collection was the NRL boom used in previous ESTCP demonstrations of the technology.

2.2.2. Positioning Technologies

Sensor positioning is provided using real-time kinematic global positioning system (RTK GPS) navigation, with real-time position updates at 20 hertz (Hz) and horizontal accuracy of about 2 cm; the dual GPS antenna configuration also provide a measure of platform azimuth and roll; the inertial measurement unit (IMU) is used to correct for platform pitch. At typical 1-3 m above ground level (AGL) operating heights, the 2 cm RTK GPS accuracy has been shown on previous deployments to translate to a horizontal positioning error of about 5 cm root mean square error (RMSE).

The GPS satellite clock time is used to time-stamp both position and sensor data information for merging channel and position data. An onboard navigation guidance display provides pilot guidance, with survey parameters established in a navigation computer that shares the RTK GPS positioning data stream with the DAS. The survey course is plotted for the pilot in real time on the display, as are presentations showing the data quality for the altimeter and GPS and the GPS navigation fix quality. Following a survey, the operator can survey any missed areas before leaving the site.

2.2.3. Data Acquisition System

A new DAS was developed by Sky Research for use with the helicopter system (Figure 3), providing the following advantages over the previous DAS used for WAA pilot program projects: smaller footprint (3.5” x 5” x 6”), Linux operating system (Realtime Linux 2.6), more accurate time stamping (10 μS) and faster sampling rate (400 Hz versus 100 Hz). The magnetometer data, logged at 400 Hz will be down-sampled to 100 Hz, providing a nominal down-the-track sample interval of 0.15 – 0.20 m per sample at a survey speed of 15 – 20 meters per second (m/s) (30 – 40 knots [kts]).

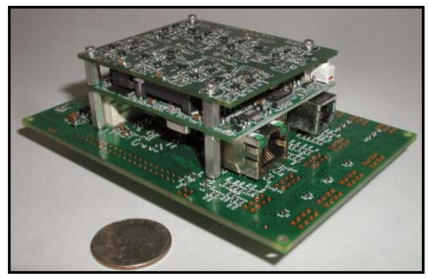


Figure 3. Sky Research, Inc. data acquisition system.

2.3. Data Processing

Data are downloaded via computer disks and uploaded via the Internet after each survey mission. SKY’s custom in-house software called SkyNet is used to transcribe, filter decimate and position the airborne geophysical data. The output from SkyNet is an ASCII xyz file that can then be imported into the Geosoft Oasis Montaj geophysical processing environment. Oasis is used to visualize the data and apply advanced processing where required. The SkyNET/Montaj combination facilitates data review, merging, correction, filtering, interpolation and target picking while also providing an industry-standard data management system. The advanced analysis of all detected HeliMag anomalies are conducted with the UXOLab software package, which is a validated, unexploded ordnance (UXO) discrimination package developed jointly by Sky Research and the University of British Columbia. The following sections describe the processing and quality control steps that were used for data processing and analysis.

2.3.1. Data Transcription/Merge

The raw data are transcribed from their native data file formats into ASCII xyz files using SkyNet. At this point, the geophysical data are subjected to a lowpass/notch filter and decimated to a sample rate of 100 Hz and assigned three dimensional (3D) positions based upon the GPS master antennae position, aircraft attitude and the system geometry. Each magnetometer reading is positioned in three dimensions by interpolating and translating the master GPS antenna position to a position for each sensor, based upon the system geometry and attitude. Because the geophysical and position data are collected asynchronously, they must be aligned with respect to their time of applicability. This is performed automatically during the merge process based upon highly precise time stamps associated with each data channel.

2.3.2. Initial Data Review/Processing

The Data Processor performs the initial review of the geophysical data. If problems exist, the Data Processor notifies the Airborne Survey Geophysicist. The Airborne Survey Geophysicist assesses the problem(s) and makes adjustments to the field operations or data processing as needed to ensure quality data collection. The sections below detail the initial review of each data type.

2.3.2.1. Geophysical Data

The initial review of geophysical (magnetometry) data ensures that the data are within a reasonable range (35,000 – 75,000 nT), are free from dropouts/spikes, and timing errors and otherwise appear to be valid. Invalid data are removed and, where appropriate, requests for re-flights are passed to the acquisition team.

2.3.2.2. Positional Data

The initial review of positional data involves checking line profiles for position dropouts/spikes. A GPS fix quality indication is recorded as part of the GPS data string. Data tagged with a fix status that indicates the GPS was not operating in ‘RTK-fix’ mode (nominally 2 cm level accuracy) are rejected automatically.

2.3.2.3. Site-Specific Processing

After the initial data review described above, the data follows a site-specific processing procedure, as discussed below.

Sensor Data Filtering

Spatial and/or time base filters are used to remove long wavelength signals from the dataset. Some of the sources of this long wavelength response are diurnal variations, geologic response,

sensor heading errors, and aircraft maneuver noise. The specific parameters of the filters are determined by site conditions such as geologic response and survey altitude above ground.

Gridding and Visualization

To convert the data into an image map, an interpolation algorithm converts xyz data into an evenly-spaced grid image at 1 m intervals. The Data Processor reviews the grids to determine the completeness and accuracy of prior data manipulation steps. A color distribution range is selected to accentuate the areas/anomalies of interest. The same color scheme is used for each block in order to avoid confusion and to enhance the ability to easily compare the anomaly densities across the site.

2.3.3. Data Analysis

The gridded total magnetic field (TMF) image is used as a basis for selection of magnetic anomalies. Automatic target selection has the advantage of being objective, repeatable and more efficient than manual selection. However, automatic target pickers are not yet sophisticated enough to reliably detect closely spaced targets or targets that are at or below the same amplitude as local geologic signal and are not able to differentiate between targets of interest and local geologic anomalies. Therefore, automatic target selection routines must only be used to select targets with response amplitudes significantly above the nominal geologic noise, otherwise an inordinate number of false targets are selected. Furthermore, the automatic routines do not perform well in areas of high target density.

For the purposes of WAA where the main goal is to delineate target density throughout the survey site, the limitations of automatic target selection are not as detrimental as they would be if we were concerned with detecting every possible UXO target. The challenge is to calibrate the automatic target selection routine so that the number of valid targets of interest selected is maximized, while minimizing the number of targets selected due to geologic noise or other noise sources (geologic noise is usually the predominant noise source). In some cases, the geology of the site may dictate that automatic target selection is augmented or even replaced by manual target selection.

The final product of a HeliMag site characterization survey is an anomaly density map. To produce an anomaly density map, a density grid is computed using a 100 m radius neighborhood kernel that assigns anomaly densities in anomalies per hectare (1 hectare = 2.47 acres) to each cell in the grid i.e., we ‘sweep’ through a 100 m radius and count the number of targets and determine the area covered (in hectares). We then calculate the density in anomalies/hectare and assign that value to the grid node. A radius of 100 m is suitable for detecting/delineating high-density areas that may be indicative of MEC-contaminated impact areas. These grids are presented for visualization using a standard color stretch of 0-250 anomalies per acre. This color stretch has been found to be ideal for recognizing and delineating ‘high concentration’ areas that

may be indicative of extensive MEC contamination (e.g., high use impact areas). Areas such as this generally have anomaly densities greater than 200 anomalies/hectare.

2.4. Factors Affecting Cost and Performance

For all airborne surveys, the largest single factor affecting the survey costs is the cost of operating the survey aircraft and sensors at the site. These equipment costs are related to capital value, maintenance overhead and direct operating costs of these expensive sensor and aircraft systems. Mobilization to and from the site increases costs as distance increases, and flexibility of scheduling is critical in determining whether mobilization and deployment costs can be shared across projects. In addition, helicopter surveys are limited by topography and vegetation and therefore can be deployed only to sites with suitable conditions.

Another significant cost factor is data volume and the requirement for a robust data processing infrastructure to manage large amounts of digital remote sensing data.

2.5. Advantages and Limitations of the Technology

As with all characterization technologies, site specific advantages and disadvantages exist that dictate the level of success of their application.

Advantages of HeliMag technologies include:

- the ability to quickly characterize very large areas; and
- lower cost as compared to ground based DGM methods.

Limitations of HeliMag technologies include:

- depending upon the site conditions this technology is not capable of reliable detection of small, individual MEC items such as 81mm mortars; and
- site physiography, such as terrain, soils and vegetation can constrain the use of the technology.

3. DEMONSTRATION DESIGN

3.1. Performance Objectives

Performance objectives are a critical component of the demonstration plan because they provide the basis for evaluating the performance and costs of the technology. For the WAA projects, both primary and secondary performance objectives have been established. Table 2 lists the performance objectives for the helicopter MTADS technology, along with criteria and metrics for evaluation, documented in Section 4.2.

Table 2. Performance Objectives

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)
Primary/Qualitative	Ease of use and efficiency of operations for each sensor system	Efficiency and ease of use meets design specifications
Primary/Quantitative	Geo-reference position accuracy	Within 0.25 m radial horizontal error and 0.5m vertical position error
Secondary/Quantitative	Survey coverage	>0.95 of planned survey area
Secondary/Quantitative	Operating parameters (altitude, speed, overlap, production level)	1-3 m AGL; 15-20 m/s (30-40 kts); 10%; 300 acres/day
Primary/Quantitative	Noise level (combined sensor/platform sources, post-filtering)	<1 nT
Secondary/Quantitative	Data density/point spacing	0.5 m along-track 1.5 m cross track
Secondary/Quantitative	MEC parameter estimates	Size <0.02 m; Solid Angle < 10º

3.2. Selecting the Test Site

The overall purpose for characterizing MEC at the Former Camp Beale is to reduce the risk of public contact with UXO through remediation activities. Current and planned development of lands within and adjacent to the Camp pose an enhanced risk to public safety that creates a sense of urgency to complete environmental remediation. Although the site underwent surface clearance in the 1950s, there remains the potential for buried UXO, something the earlier sweeps were not equipped to detect.

The entire Former Camp Beale demonstration site comprises regions where the topography and vegetation are not amenable to HeliMag surveys. A site suitability model (Figure 4) was derived from existing LiDAR data to delineate areas that were amenable to HeliMag survey flights. In addition, ground magnetometry profile data collected during advanced site visits indicate that a significant portion of the site is characterized by magnetically active geology. One of the goals of the demonstration was to evaluate the limitations to the HeliMag technology imposed by the geology. Accordingly, out of the 5,000 planned survey acres, it was decided that a significant percentage of these acres should include regions with challenging geology. Because no prior knowledge of the spatial distribution of magnetically active geology was available, a reconnaissance survey was flown over suitable terrain across the site at 500 m line spacing. The initial boundaries for the reconnaissance flights were derived using the site suitability model. The results of the reconnaissance flights were in turn used to derive the final survey areas in consultation with the ESTCP Program Office (shown in Figure 5)

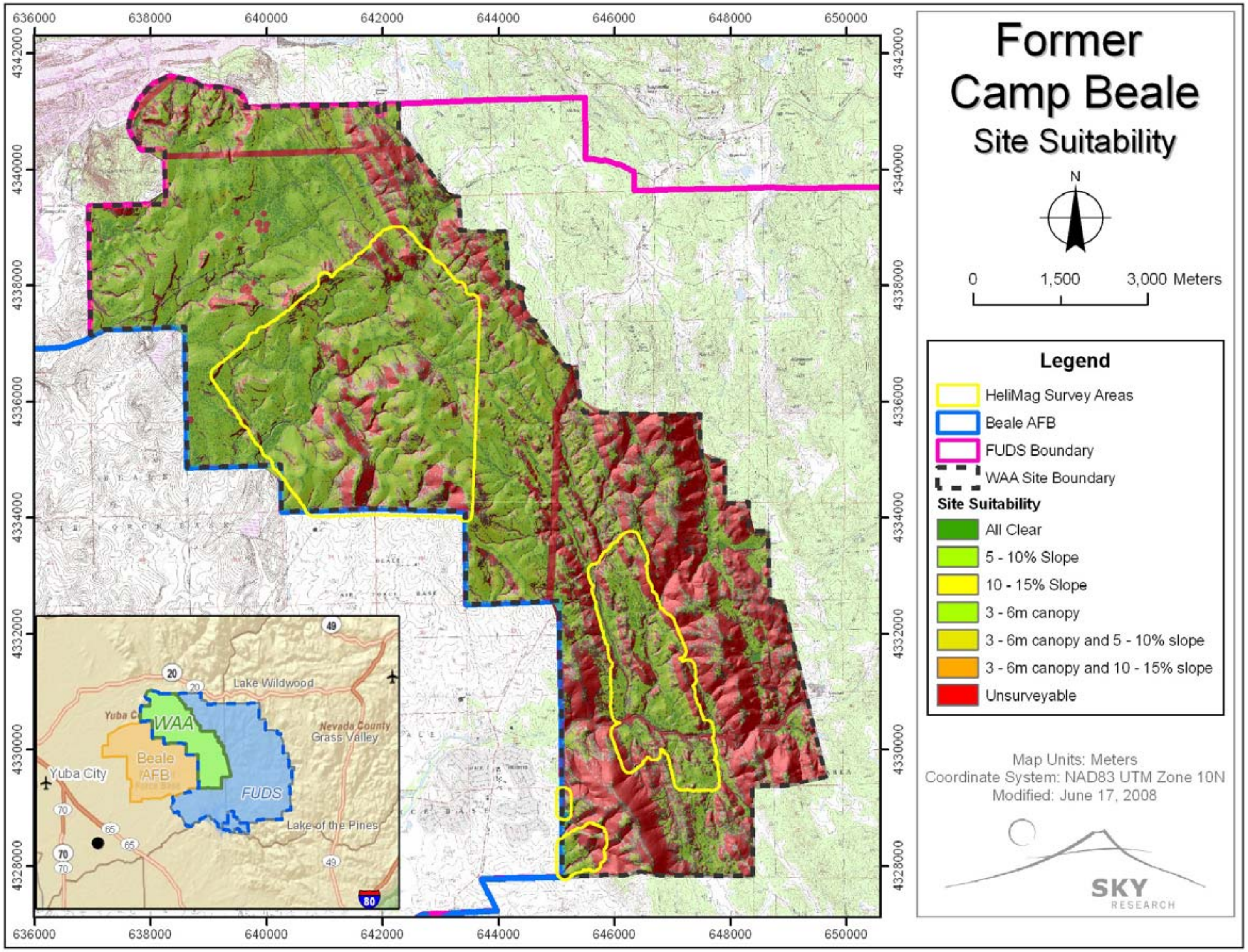


Figure 4. HeliMag site suitability model and reconnaissance survey boundaries for the Former Camp Beale demonstration site.

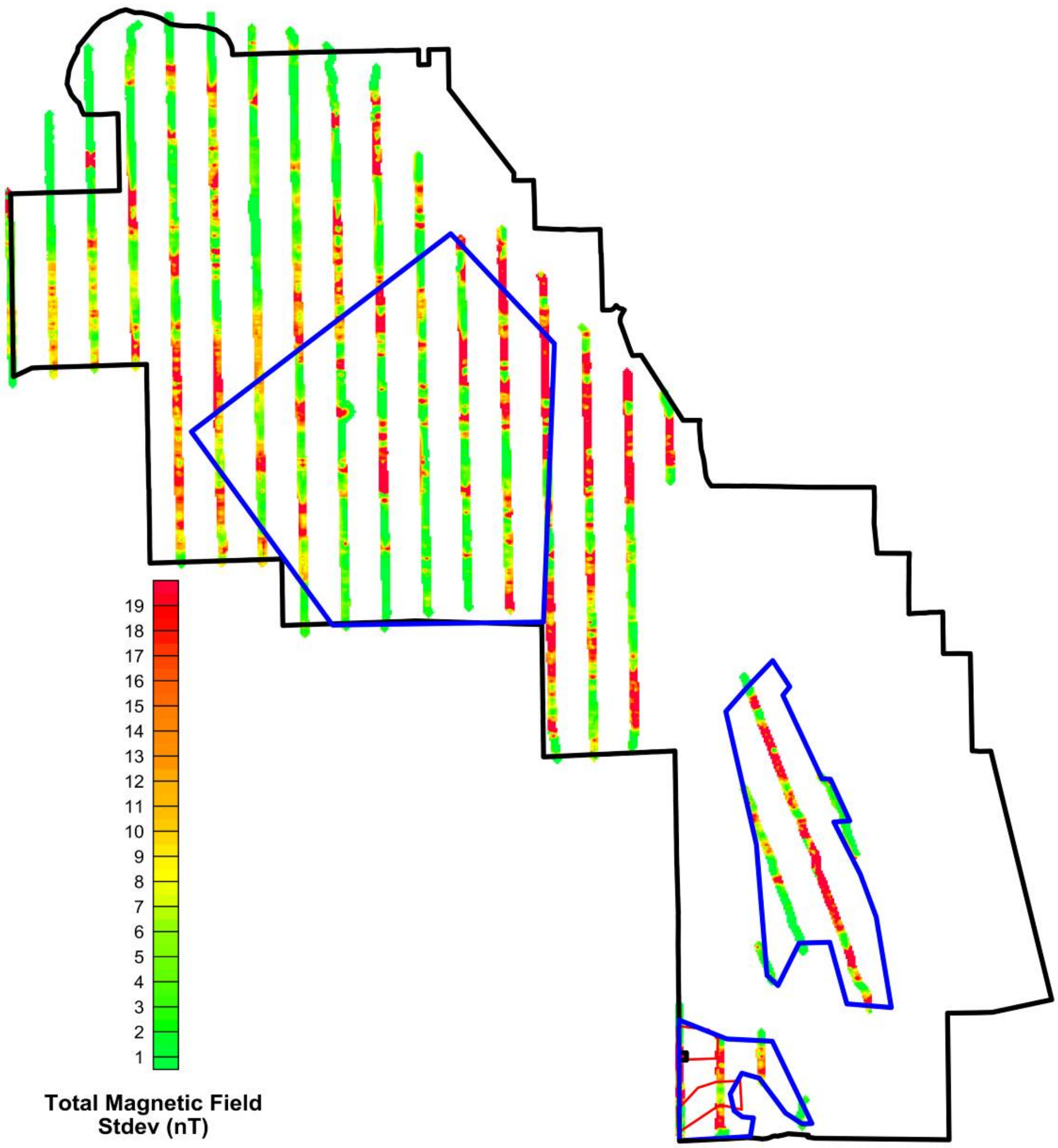


Figure 5. Reconnaissance survey results and final planned HeliMag survey boundaries (outlined in blue).

3.3. Test Site History/Characteristics

The Former Camp Beale site encompasses approximately 64,000 acres located in northern California immediately east of Beale Air Force Base, straddling both Yuba and Nevada counties. The site is located approximately 45 miles north of Sacramento and 20 miles east of Marysville.

In 1940, the Camp Beale area consisted of grassland and rolling hills and the abandoned mining town of Spenceville. With the urging of Marysville City officials, the Department of War established a military facility in the area. The U.S. government purchased 87,000 acres in 1942 for a training post for the 13th Armored Division, the only unit of its kind to be entirely trained in California. Camp Beale also held training facilities for the 81st and 96th Infantry Division, a 1,000-bed hospital, and a prisoner of war camp. Dredge materials from the area's abandoned gold mines were used to build streets at the Camp.

As a complete training environment, Camp Beale had tank maneuvers, mortar and rifle ranges, a bombardier-navigator training, and chemical warfare classes. During WWII, Camp Beale had 60,000 personnel.

In 1948, Camp Beale became Beale Air Force Base (AFB), its mission to train bombardier-navigators in radar techniques. The Base established six bombing ranges of 1,200 acres each. The U.S. Navy also used Beale AFB for training. From 1951 on, Beale trained navigation engineers and ran an Air Base Defense School. These additional activities led to rehabilitation of existing Base facilities and construction of rifle, mortar, demolition, and machine gun ranges. In 1958 the first runway was operational.

One year later, the installation stopped being used as a bombing range and the U.S. Government declared portions of Camp Beale/Beale AFB as excess, eventually transferring out 60,805 acres. On December 21, 1959, 40,592 acres on the eastern side of the Base were sold at auction. An additional 11,213 acres was transferred to the State of California between 1962 and 1964, and now comprise the Spenceville Wildlife and Recreation Area. In 1964-1965, another 9,000 acres were sold at auction. In deeds for the Former Camp Beale property, the Federal Government recommended that the property have surface use only. When the Former Camp Beale was returned to non-military use, the Army swept the surface of a number of target areas using trucks (where terrain permitted) and on foot to search for UXO. Nearly 500 potentially explosive items were recovered, over two-thirds of them small spotting charges. Since then, potential UXO items have been turned in occasionally to law enforcement officials or to the ordnance specialists at Beale AFB.

Topography and Soils. The principal physiographic units at Former Camp Beale are the dissected alluvial uplands west of the Sierra Nevada, the foothills section of the Sierra Nevada, and the Sierra Nevada Mountains. The dissected alluvial uplands consist of low hills and gently rolling country that merge with the foothills of the Sierra Nevada on the east, and the low alluvial plains of the eastern Sacramento Valley on the west. The

foothills lie to the east of the alluvial uplands and are an undulating to very steep region at the base of the Sierra Nevada Mountains. While the presence of low hills and gentle slopes does not pose constraints to safe and effective HeliMag data collection, steep slopes and mountainous areas cannot be surveyed; the final survey site selection reflected this limitation.

The alluvial uplands are underlain by silty sands with gravel which cover the weathered granite bedrock surface. The foothills of the Sierra Nevada are underlain by sandy and gravelly silts covering vertically tilted metamorphic rock. The near-surface stratigraphy of the lower Sierra Nevada Mountains within Former Camp Beale consists of rolling to steep soils and rock outcrops on mountainous uplands. On all these soil types, the rate of permeability is moderately rapid, creating a moderate hazard of erosion. In addition, these soils are moderately corrosive to uncoated steel.

The top soil is thin and solid, if it exists at all. Solid rock formations often protrude from the grass-covered surface. For these reasons, as stated in the ASR, the chances of ordnance burying itself below the surface are remote. The hard surface and low level of erosion make the ground surface very difficult to crater, and yet once cratered, the surface would stay that way for a long time.

Climate and Hydrology. The regional climate of the Former Camp Beale area is classified as Mediterranean, characterized by cool wet winters and warm dry summers. Typical dry summers are the result of a semi-permanent high-pressure cell located over the eastern Pacific Ocean that generally blocks storms from moving into the air basin the summer months. Climatic regimes did not pose any restrictions to HeliMag data collection at this site.

There are three permanent streams in the Former Camp Beale: Bear River, Dry Creek, and Rock Creek. Bear River discharges are regulated by upstream reservoirs and diversions. Dry Creek and Rock Creek, tributaries of Bear River, drain the eastern two-thirds of Former Camp Beale. Several smaller streams drain the western third of the Camp area: Reeds Creek and Hutchinson Creek head in the hilly lands along the northern boundary and flow westerly across the gently sloping valley plains during the winter and spring months.

Ponds in the Former Camp Beale area are all man-made, including Camp Far West Reservoir and several stock ponds. Camp Far West Reservoir borders the southern boundary of the Camp; it is a water supply reservoir owned by South Sutter Water District.

Vernal pools have been observed in the northwestern and southwestern portions of the Former Camp Beale. Vernal pools usually are found in gentle topography, often surrounded by annual grasslands. These ephemeral wetlands form in depressions that fill with winter rainwater and then dry completely during the late spring and early summer. The combination of saturated conditions alternating with an extended dry period requires

specialized adaptations, and many species have evolved to exist and thrive only in this unique habitat.

The summer timing of the HeliMag survey at the Former Camp Beale did not negatively impact these sensitive aquatic habitats.

Vegetation. The predominant vegetation communities present at the Former Camp Beale are grasslands, savannahs and woodlands, wetlands (including marshes, ponds and vernal pools) and riparian habitat. Annual grasslands are uplands dominated by herbaceous (non-woody) plant species that grow during the winter rainy season and then become dormant during the dry summer months (Figure 6). Savannas are open, tree-dominated habitats with a grassy under story, while woodlands have denser tree cover with a grass or shrub under story. In the Former Camp Beale, savannas and woodlands are generally found in the rolling topography above the valley floor (Figure 7). The most common tree in this area is blue oak, but other trees include valley oak, interior live oak, California buckeye, gray pine, and ponderosa pine. Permanent wetlands and marshes throughout the Former Camp Beale are characterized by plant species such as cattails, bulrushes, tulles, and sedges. They are generally found at the margins of permanent lakes, ponds, and waterways. Riparian habitats are associated with streams. In the Former Camp Beale, typical riparian plants are Fremont cottonwood, valley oak, alder, Oregon ash, willows, and elderberries.

HeliMag surveys cannot be conducted in areas with trees or tall shrubs; the presence of these vegetation components is a constraint to use of the technology in those areas. This was factored into the selection of survey locations.

Land Use. Former Camp Beale is currently used primarily for agriculture (cattle and horse pastures, with some limited orchard and planting activities); as such, most of the property is open space. Parts of the Former Camp Beale have been and are being proposed for residential and commercial development. As encroachment by urbanization continues to expand, habitation and recreation will become the dominant use of the land.

Figure 6. Grasslands and oak savannah woodlands at Former Camp Beale.

Figure 7. Terrestrial vegetation at Former Camp Beale.

3.4. Pre-Demonstration Testing and Analysis

Helicopter magnetometry technology has been fully evaluated by DoD through ESTCP. As a WAA tool, the NRL MTADS has been previously demonstrated at other WAA pilot program sites, including: Kirtland Precision Bombing Range, NM; Victorville Precision Bombing Range, CA; and Pueblo Precision Bombing Range, CO. Additionally, Sky Research has begun deploying an updated helicopter-borne magnetometry sensor system to U.S. Air Force sites under the Air Force's Military Munitions Response Program, including Edwards AFB, CA; Kirtland AFB, NM; and Vandenberg AFB, CA. Both versions of the technology have been tested at the Sky Research test site in Ashland, Oregon. Results from surveys of validation items used for WAA demonstration projects were analyzed in 2006 to compare the two system's capabilities. These results of the side-by-side comparison of validation lane flights conducted at the SKY test site on both versions of the technology were submitted to ESTCP in 2006.

3.5. Testing and Evaluation Plan

3.5.1. Demonstration Set-Up and Start-Up

Mobilization for this project required:

1) Mobilization of the equipment, pilot, and sensor operators.
2) Deployment of ground-support personnel to establish ground fiducials, establish and operate GPS base stations, establish validation line location and collect data on validation location, and provide logistical support.
3) Establishment of validation line and standard pre-collection maintenance and validation procedures established during previous deployments.

A base of field operations was established at the Yuba County Airport, providing fuel and temporary hanger/storage space during operations at the site.

Ground Control

The Sky Research in-house professional land surveyor was used to establish control point coordinates so that the geospatial data were tied into the proper coordinate system. Both the HeliMag data and the ground truth/validation targets were positioned using RTK GPS to provide centimeter-accuracy positioning. All of the geospatial data are positioned in meters relative to the WGS84 Ellipsoid using the UTM zone 10N projection.

Sensor Validation Lanes

Two validation lanes, oriented north-south, were established at Former Camp Beale for the purpose of establishing that the HeliMag system was operating within the proper parameters. The first validation lane was determined to be in an area of complex geology and the data were not useful. The second lane was established on Day 5 of the data collection and was used for the remainder of the survey. This lane was seeded with 8 targets comprising four unique types of items (Table 3). The validation lane was flown on each day of data collection to verify that the sensors were operating correctly and the positioning of the data was consistent and within the specified parameters for the system. Typically, weather-permitting, these validation flights occurred twice per day to ensure that the sensors responded in the same ways at both the beginning and end of each data collection day. Note that the validation lane is used only to monitor system performance on a daily basis; it is not intended as a Geophysical Prove Out. No targets were buried and no attempt was made to measure a probability of detection.

Table 3. Validation Items Seeded in Validation Lane #2

ID	X	Y	Elevation	Azimuth	Description
1	126320.28	4343387.84	137.29	27.5º	Metal Cache box
2	126325.45	4343402.43	138.20	27.5º	2.75” rocket
3	126331.61	4343416.22	139.27	25º	155 mm projectile
4	126336.76	4343430.39	140.30	20º	Simulated 100-lb. bomb
5	126341.66	4343444.53	141.66	110º	Metal Cache box
6	126347.38	4343458.68	143.13	120º	2.75” rocket
7	126353.01	4343472.63	144.43	117.5º	155 mm projectile
8	126358.75	4343486.79	146.09	110º	Simulated 100-lb. bomb

3.5.2. Period of Operation and Survey Coverage

Data collection occurred from June 29 to July 19, 2007, and was completed in 17 flight days. During this time, 4,417 acres were surveyed (Figure 8) resulting in productivity of 259 acres per flight day. The airborne survey crew consisted of one pilot and one system operator.

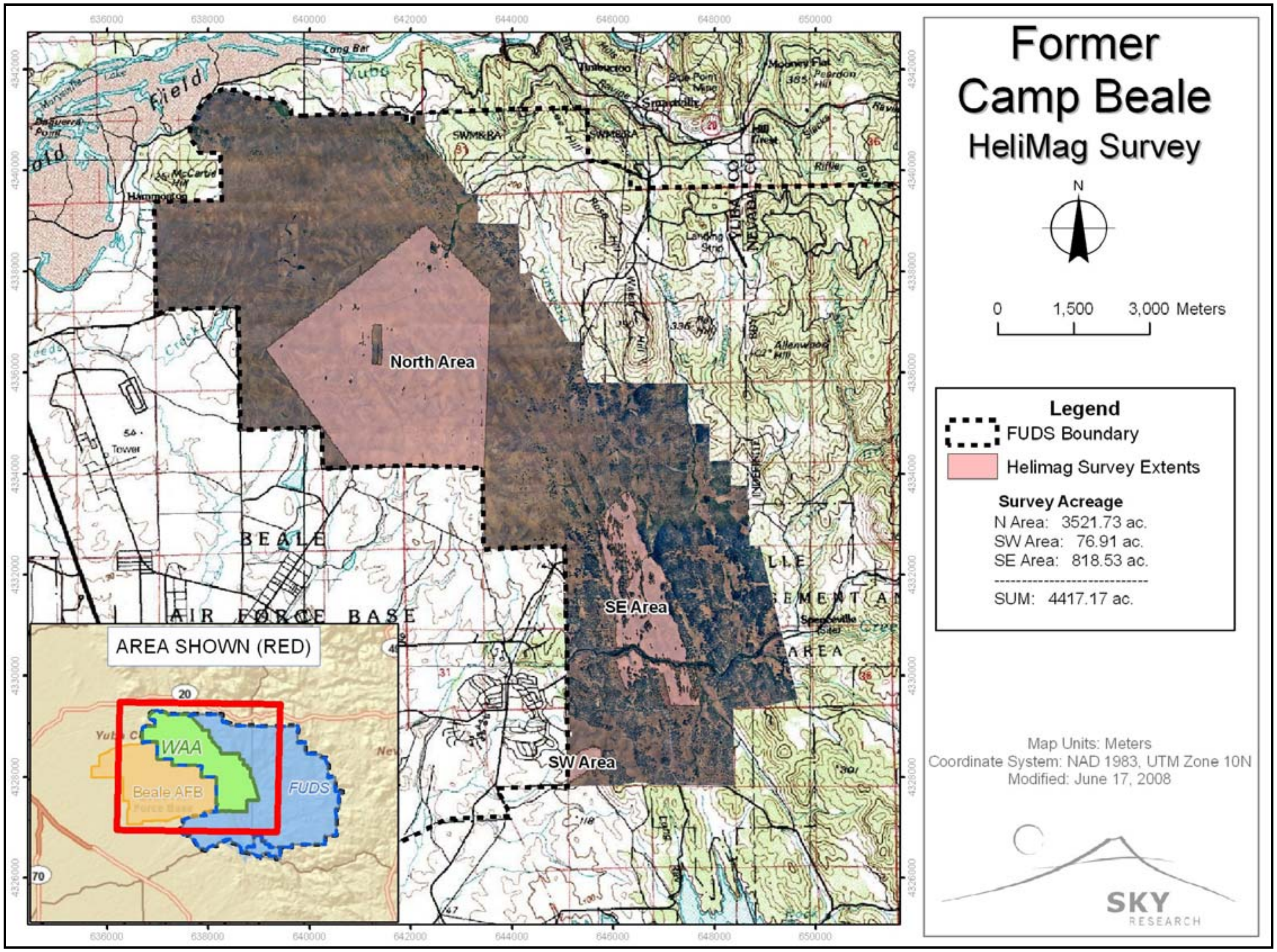


Figure 8. Final low-level survey coverage. Data collected at over 4 m AGL have been defaulted.

3.5.3. Operational Parameters for the Technology

Sky Research deployed the airborne MTADS system on a Hughes MD500D helicopter platform, together with a pilot and system operator. A ground support team operated the RTK GPS base stations. The helicopter was flown at a low altitude (1-3 m), with a forward velocity of 10 - 20 m/s.

As described previously, seven total-field Cs vapor magnetometers were deployed on the 9 m boom mounted transversely on the front of the helicopter skids. The magnetometer data were logged at 400 Hz and de-sampled to 100 Hz during post processing. With the sensor spacing of 1.5 m and a speed over ground of 15 m/s, the resulting data density provides a minimum of 50 data points on a typical target to fit the dipole signature. The aircraft flew traverse lines over the area evenly spaced at 7 m. This spacing provides considerable overlap (28%) but is necessary to ensure complete coverage because of the degree of difficulty involved in flying perfectly straight lines under real world conditions.

3.5.4. Data Processing/Analysis

The data from each day of surveying were downloaded and processed each evening by a dedicated data processor. The processing was performed as described in Section 2.3. Up-to-date ‘final’ quality TMF maps were produced within less than 12 hours after data collection. Timely processing of the data allowed for near real-time monitoring of daily production as well as provided feedback with respect to the system performance.

Due to the pervasive presence of challenging geology, manual target selection was used to create the target list. This target list then served as the basis for the metal density analysis. Detailed discussions of the final data and target density analysis are presented in Section 4.3.4.2.

3.5.5. Demobilization

At the conclusion of the surveys, the helicopter, associated equipment, and field crews were demobilized from the site. No remediation of identified MEC was implemented.

4. PERFOMANCE ASSESSMENT

4.1. Validation Line Results

Although the second validation line had a relatively small magnetic signature due to geology, 3 of the 8 targets were co-located with a magnetic feature of unknown origin. These 3 targets (numbers 6 through 8) were excluded from the analysis of the validation line results. The data collected over each target from the validation line passes that were assumed to be valid (i.e., target positions are stable and data positioning quality is good) were analyzed using the UXOLab dipole fit analysis algorithm. This analysis derives the parameters for a model dipole that best fits the observed data. These parameters include horizontal position, depth, size, and solid angle (i.e., the angle between the Earth's magnetic field vector and that of the dipole model). The derived parameters were examined for accuracy (determined as the average error where relevant) and repeatability (indicated by the standard deviation), as presented in Table 4.

Table 4. Validation Results for Validation Lane Targets

Dipole Fit Parameter	Bias	Standard Deviation
Easting	n/a	0.20 m
Northing	n/a	0.14 m
Depth	0.19 m	0.22 m
Size	n/a	.011 m
Solid Angle	n/a	8.75º

Under normal circumstances, the position accuracy would be very easy to determine and very relevant to any discussion of the system performance. However, it appears that the ground truth coordinates supplied for each target are not reliable. The positions for each target appear to have a repeatable bias (Figure 9).

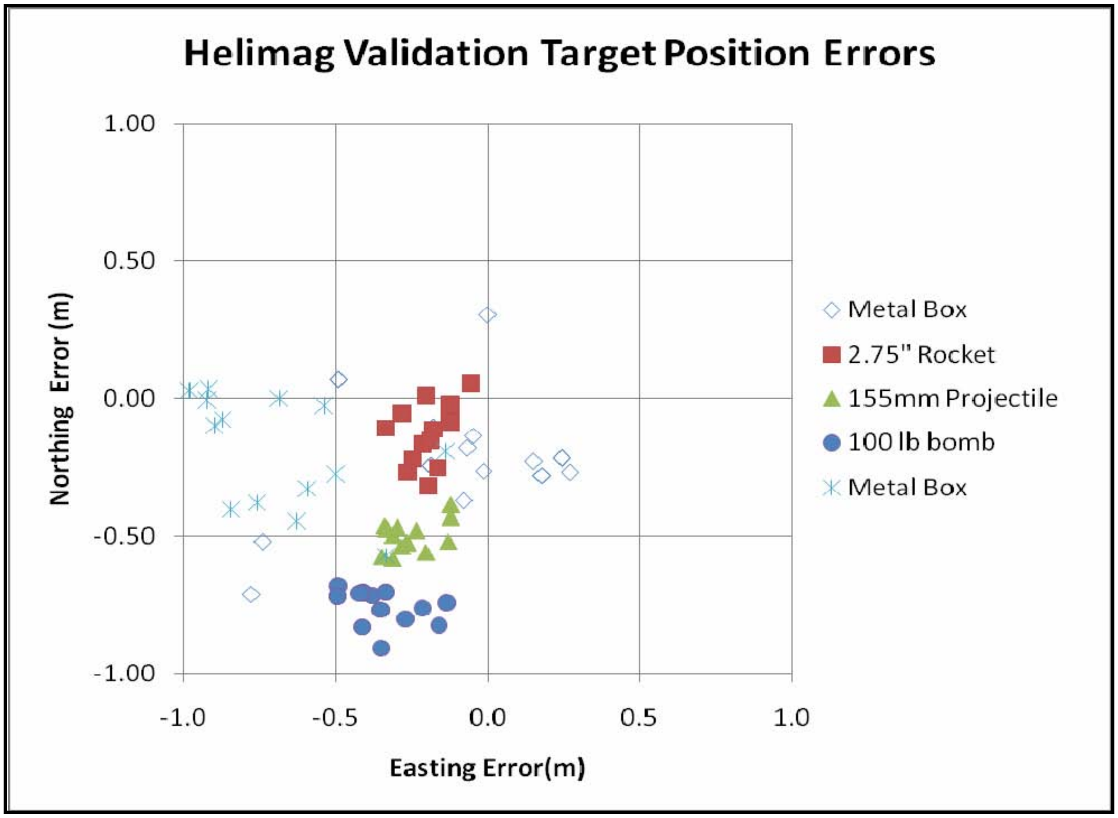


Figure 9. Derived x and y coordinates for the validation targets relative to the supplied ground truth

In Figure 10, the derived positions for each target with the bias removed are shown. The increased noise in the easting is assumed to be a result of the relative sample densities for each direction (validation lines were flown in a north-south direction and along-track sample density is 5 to 10 times higher than for across-track).

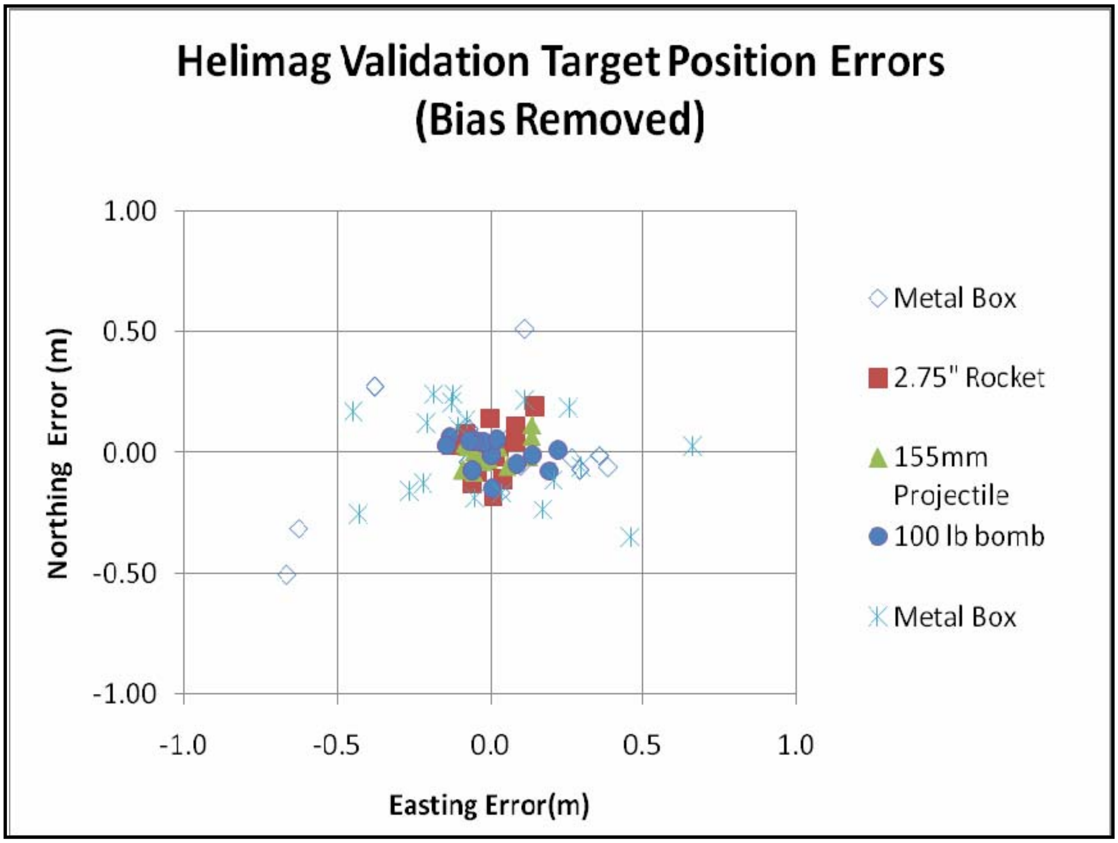


Figure 10. Derived x and y coordinates errors for the validation line targets with position bias removed.

In the dipole fit depth estimates (Figure 11) it appears that the depths are too deep by an average of 0.19 m. This may be attributable to target position ground truth measurement error (similar to the horizontal biases noted above), or inherent limitations in the accuracy of the depth estimates. The depth estimates are equal to the DEM HAE minus the dipole-fit derived target HAE. Thus local errors in the DEM will persist in the final target depth estimate. Additionally, the fact that we collected data in effectively a plane over the target, caused the target fit position in the z direction to be the least well-constrained position fit parameter. For these reasons, the vertical position accuracy objective of 0.5m is twice that of the horizontal position objective

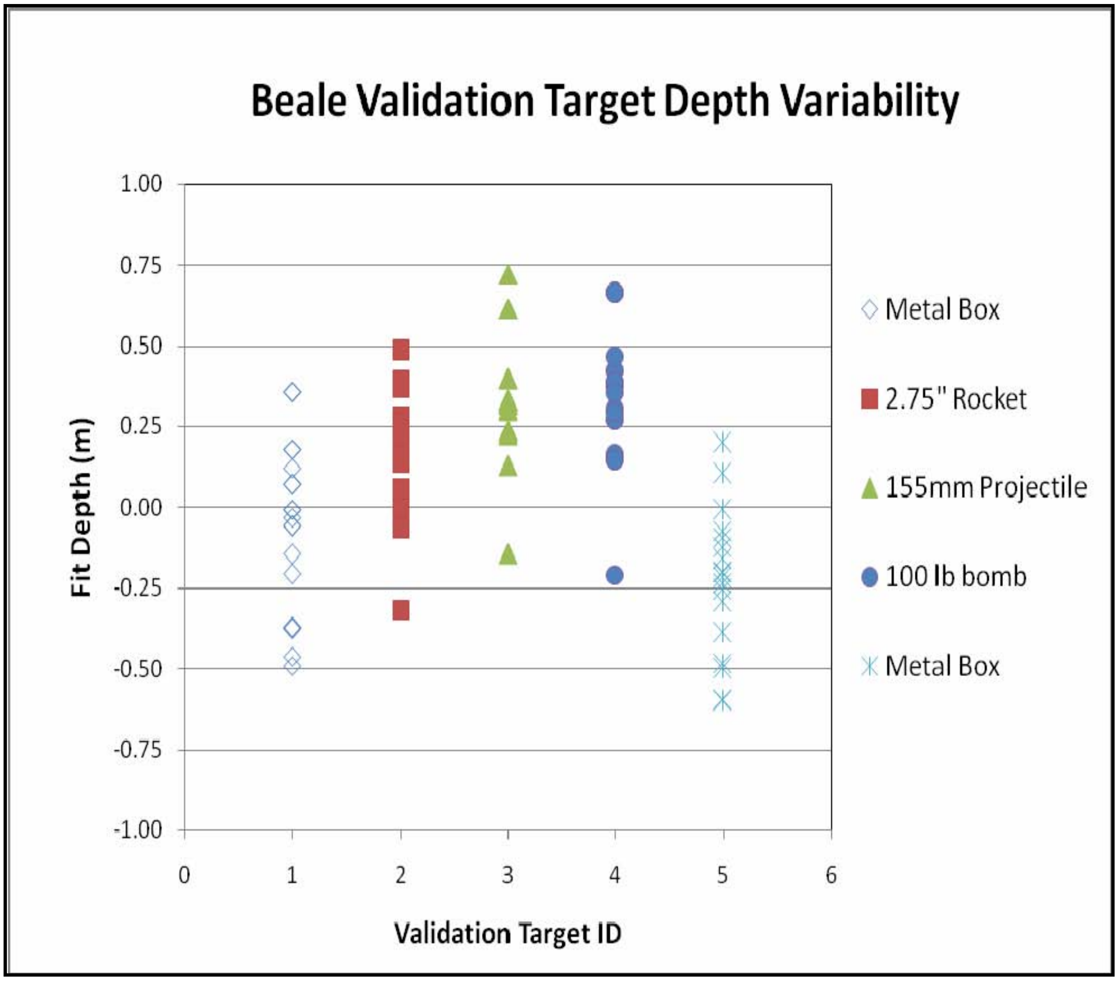


Figure 11. Dipole depth estimate errors for validation line targets. These errors are calculated as the difference between the estimated target depth, and the actual depth of each target. Because the targets were on the surface, their actual depth is assumed to be minus ½ of the target diameter

The dipole fit size estimate for any given ordnance will vary considerably depending upon the alignment of the object with the Earth's magnetic field. Therefore, the size can only be used as a coarse estimate of the object size. For this reason, the accuracy of the size estimate of the validation items is not of particular import when discussing the system performance, other than simply verifying that the estimate falls within the expected range for a given target (which they do, as shown in Figure 12). Because the validation data consist of repeated flights over the same stationary targets, the repeatability of the derived size estimates can be used as an indication of consistent system performance. The average size for each specific target was removed from the target size estimates before the standard deviation for the entire set of size estimates was calculated. The variability in the size estimates is a little greater than would be expected. Most of this variability occurs with the smaller metal box targets and is attributed to the relatively low signal to noise ratio of the magnetic measurements for these targets.

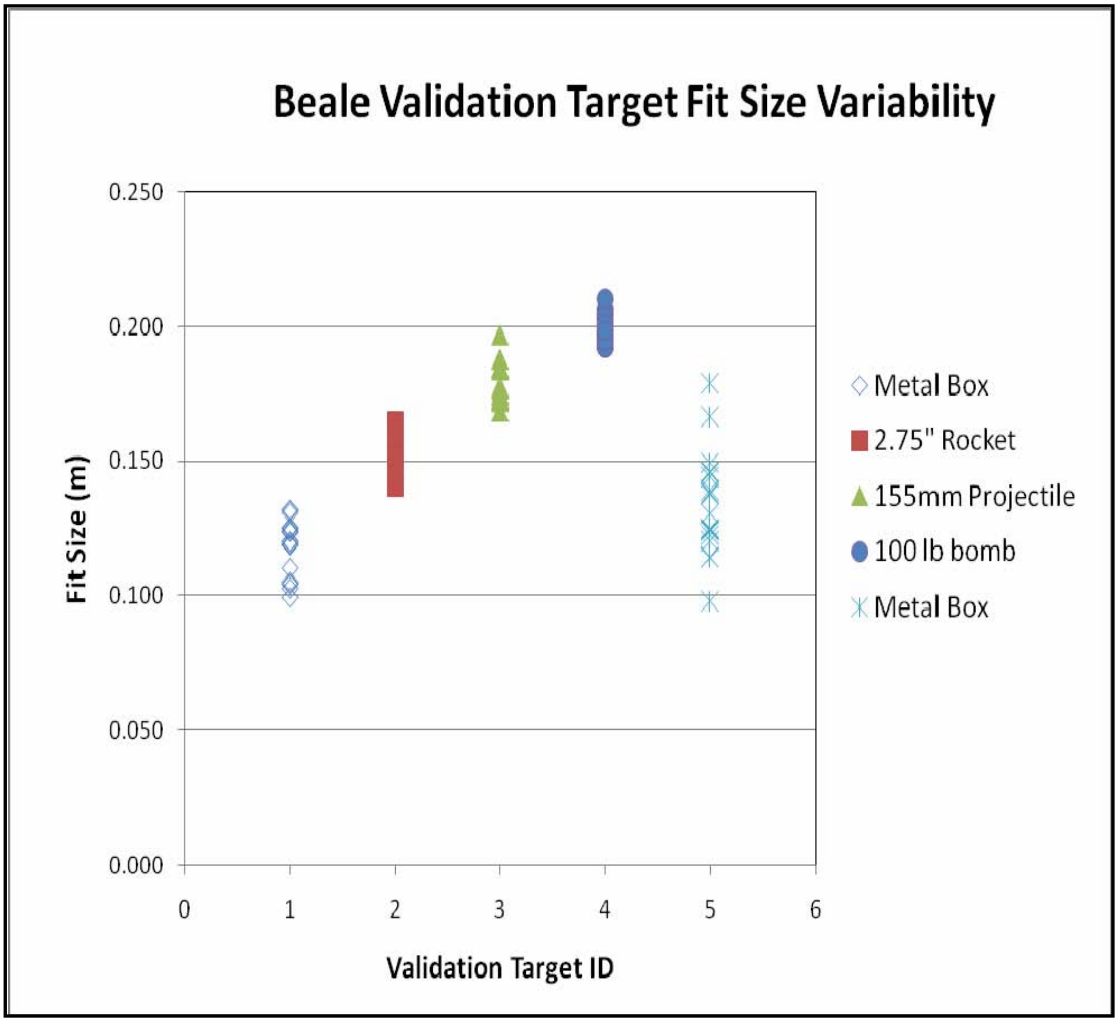


Figure 12. Dipole fit size estimates for validation line targets.

In a manner similar to the size estimates discussed above, the dipole fit solid angle estimates depend heavily on the orientation of the target relative to the Earth's magnetic field. In the case of the validation line test targets, the 'ground truth' is unknown and not really important. However the stability of this prediction for repeated flights over the validation line is indicative of the performance of the airborne system (Figure 13).

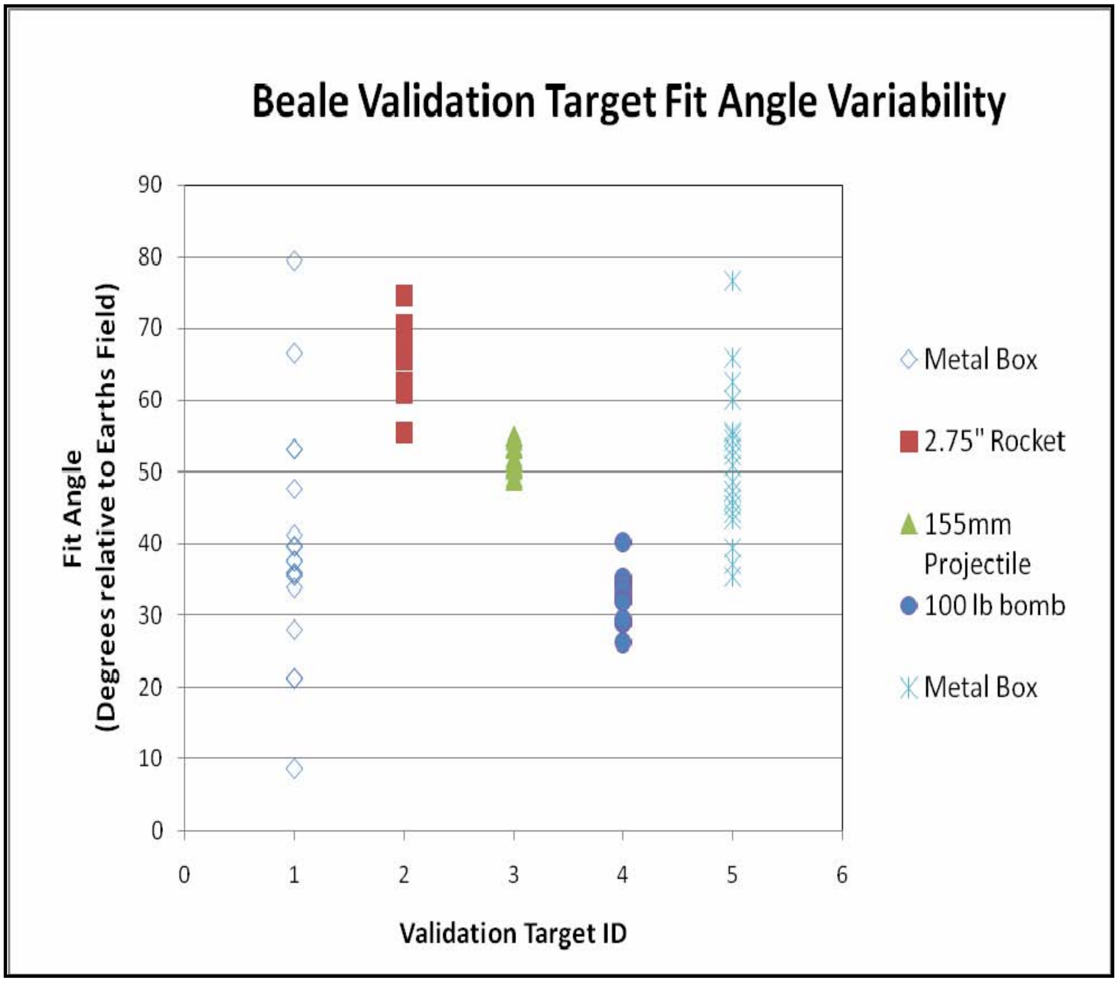


Figure 13. Dipole fit solid angle (dipole angle relative to the Earth's field) for validation line targets

4.2. Performance Confirmation Methods

Table 5 details the confirmation methods that were used for each criterion, the expected performance, and the performance achieved.

Table 5. Performance Metrics Confirmation Methods and Results

Performance Metric	Confirmation Method	Expected Performance	Performance Achieved
Technology Usage	Field experience using technology during demonstration	Relative ease of use	Pass
Geo-reference position accuracy	Infer sensor position accuracy from position estimates of validation targets derived using dipole analysis of repeated data collection over validation targets	Horizontal < 0.25 m Vertical <0.5 m	Horizontal: 0.24 Vertical: 0.22
HeliMag survey area coverage	The sum of actual areas surveyed calculated in a geographic information system (GIS) and compared to the final survey area.	95%	98.7%
Operating parameters (altitude, speed, overlap, production level)	Field data logs and/or final survey databases used to calculate the operating parameters	Altitude: 1-3 m AGL Speed: 10-20 m/s (20-40 knots) Production 300 acres/day	Altitude: 1.8 m agl Speed: mean 13.2 m/s, Production: 259 acres/day
System Noise	The system noise was calculated as the standard deviation of a 20 sec window of processed high-altitude data.	<1 nT	0.22 nT
Data density/point spacing.	Calculated based upon system sample rate and survey speed (along track) and system geometry and survey line spacing (cross-track track).	0.5 m along-track 1.5 m cross-track	Along-track: Mean 0.13 m max 0.29 m Cross-track: Max: 1.5 m
MEC parameter estimates	Comparison of analysis results of repeated data collected over validation targets.	Size: <.02 m Solid Angle: < 10 º	Size: 0.011 m Solid Angle 8.75 º

Position accuracy on a dynamic platform is very difficult to measure precisely. We are able to infer the position accuracy of the sensor data by using the position estimates derived from dipole fit analysis of data collected over known targets. Although there are additional error sources (other than just those due to the data positioning) in the dipole fit results, they are almost negligible due to the stability of the magnetometer calibration and the robustness of the dipole fit process. Because reciprocal passes will tend to hide along-track position errors (due to the robustness of the dipole fit process), the dipole fit analyses were performed on a single pass over the targets.

The spatial extent of a magnetic anomaly (from our targets of interest) is a factor of two times greater than the sensor offset distance. Based upon our minimum survey height of 1.5 m, we can conservatively define gaps in survey coverage as areas where the distance to the nearest sensor reading is greater than 2 m. Gaps in survey coverage are generally related to navigation (a combination of pilot skill, topography/vegetation, and wind conditions) or data integrity (primarily GPS fix quality). As a general practice, images representing the data from each day of survey flying are created to identify areas requiring fill-in flying to cover significant gaps in coverage. Invariably there will be a number of gaps in survey coverage that cannot be practically filled. To estimate the survey coverage performance, at every 0.25 m interval (grid node) we search through a 1 m radius for a valid data point. The number of grid nodes where valid data are found is divided by the total number of grid nodes to derive the percentage of survey coverage. Based upon these factors and acreages, the final coverage was 98.7%.

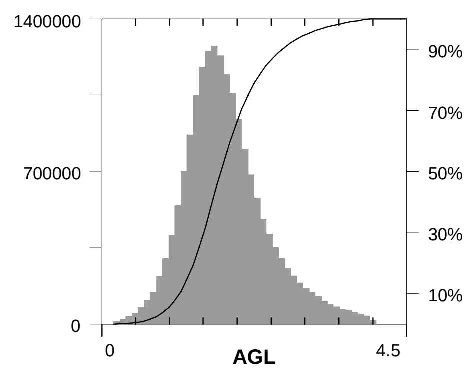


Figure 14. Histogram of sensor altitude above ground level.

The assessment of the survey altitude and speed was performed by extracting statistics for these parameters from the survey databases. Survey speed was consistently maintained between 20 and 50 kts (10 – 25 m/s), with some insignificant variation at the beginning or end of the survey lines. Survey altitude is a critical parameter for this type of investigation and is expected to be a little more variable than survey speed. In Figure 14, we present a histogram of the survey altitude performance. As with presentation/analysis of the results, prior to deriving these statistics, all altitudes above 5 m were rejected. These altitudes generally occur at the end of survey lines or during times when the helicopter has broken off a survey line and is circling back to reacquire it. The mean survey altitude was 1.8 m and the standard deviation was 0.61 m.

The survey production acreage of 239acres/day was less than the expected performance of 300 acres/day. The lower production was primarily a result of the high temperatures (average 94°f and some days were more than 100°f) which necessitated flying with less fuel (the MD500D model used for this survey has reduced lift performance relative to the

MD500F model used by Sky Research on other surveys). This shortened endurance required twice the number of refueling stops for any given day. Additionally, on windy days the survey lines were flown in a single direction, thus further reducing the productivity levels.

HeliMag system noise levels were determined by calculating the standard deviation of a 20 second window of the final filtered magnetic data flown at high altitude out of ground effect. The noise varied by sensor/orientation with the Earth's field. Typical results varied from 0.10 to 0.22 nT. Figure 15 depicts a typical stretch of high altitude data.

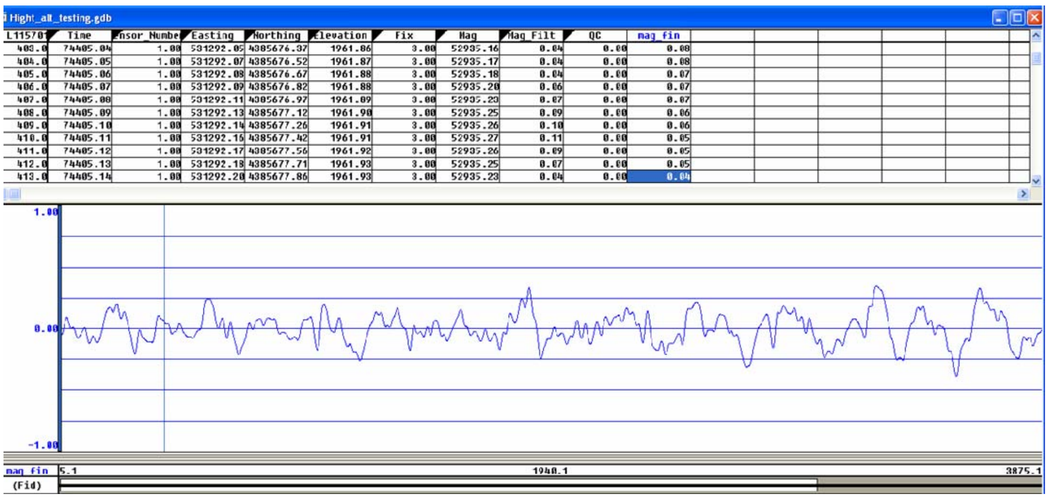


Figure 15. 38 second sample of high altitude, 'final' filtered data.

The cross-track data density is essentially static and is a function of the system geometry. With the exception of isolated data gaps (addressed above) the 'worst case' spacing is our sensor spacing of 1.5 m. The effective density is much higher than this due to the significant overlap required to ensure (or at least minimize) data gaps due to the inevitable cross-track variation of the helicopter flight path. However, because the density is not uniform, we quote the 'worst case' as the data density achieved. Down-track data density is much higher than the cross-track density and is a function of survey speed. At our final sample rate of 100 Hz, the survey speeds of 10 – 25 m/s (20 – 50 kts) resulted in down-line data spacing of 0.10 - 0.25 m.

4.3. Survey Results

4.3.1. Final Survey Coverage

Due to unforeseen scheduling conflicts the helicopter provider was forced to call for return of the helicopter prior to completion of the entire planned acreage. As a result, the Southwest area was not fully covered. Including the reconnaissance transects 4,814 of the planned 5,231 acres were covered (excluding the reconnaissance transects: 4,417 of the planned 4,834 ‘full coverage’ acres). Table 6 summarizes the acreage covered by area.

Table 6. Survey Acreages by Area.

Area Name	Planned	Actual
Recon (transects)	397	397
North	3,522	3,522
Southeast	992	819
Southwest	321	76
Total (acres)	**5,232**	**4,814**

The decision was made to not remobilize and collect the remaining acreage. The challenging terrain and geology in the southwest area are less than ideal and the resulting data quality would not justify the cost of remobilization.

The final total magnetic field data and survey coverage are shown in Figure 16. Areas with linear bands of very high and very low amplitude magnetic response (that effectively look purple on the color image as seen in the northeast corner of the North area (Figure 16) are regions we considered having ‘extreme’ geologic response. Other regions that have multiple large amplitude anomalies that are more localized and do not exhibit the same banding are considered to have ‘moderate’ geologic response (e.g., the northwest corner of the North area shown in Figure 16). Clearly, the geologic response will interfere with our ability to detect UXO-like anomalies.

The presence of challenging geology dictated that the anomalies were selected manually. A total of 9,544 targets were selected in the North area, 2,503 targets in the Southeast area and 388 in the Southwest area.

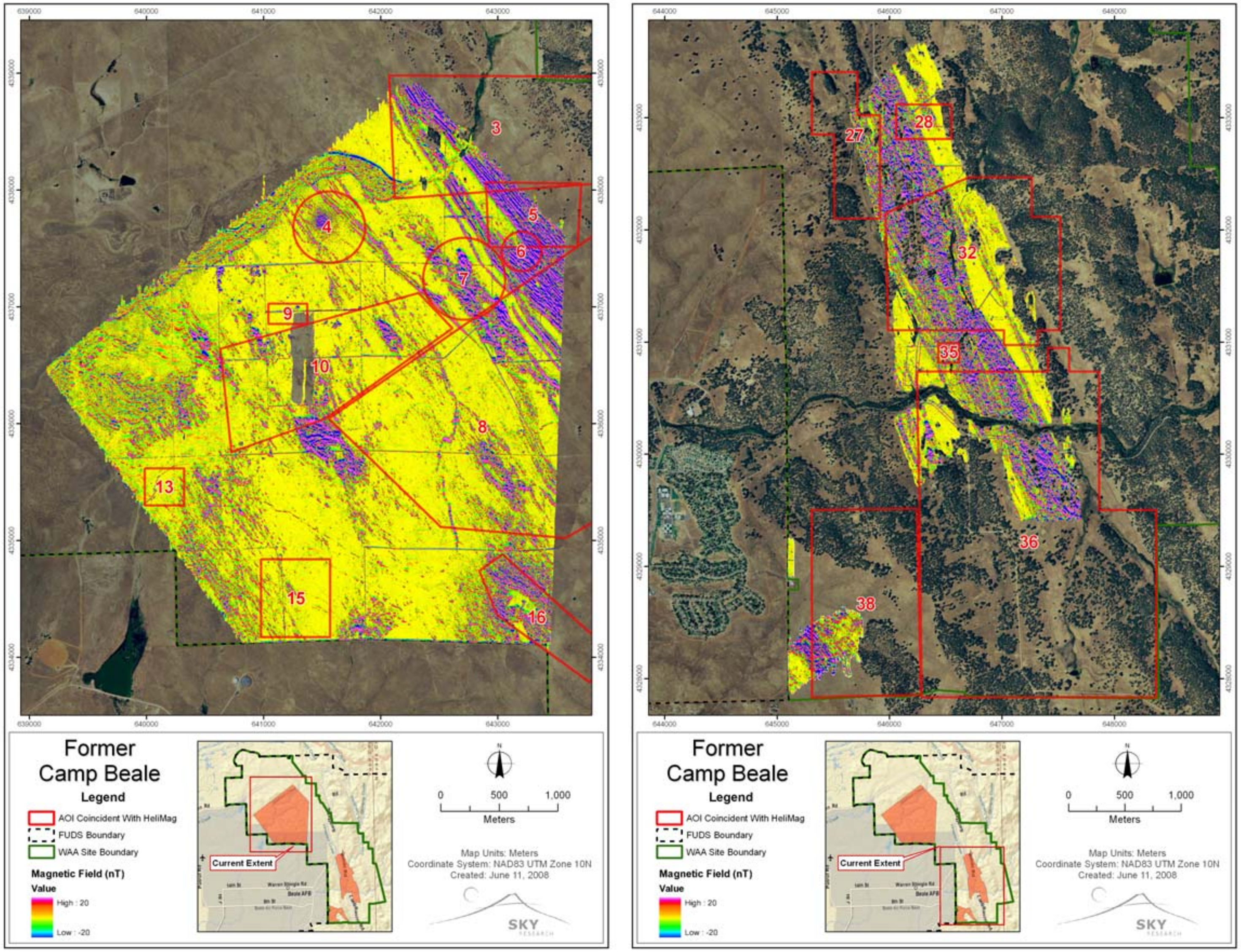


Figure 16. Total magnetic field results for the HeliMag survey at the Former Camp Beale.

4.3.2. Anomaly Density Analysis

To visualize the distribution of metal objects across the study area, a density raster was computed using a 100 m radius neighborhood kernel that assigned anomaly densities in anomalies per hectare to each cell in the raster. Simply described, at grid nodes of every two meters the number of targets that appear within a 100 m search radius were counted. This search radius provides the density in targets per 31,416 m^2. These values were then ‘normalized’ by dividing by 3.1416 to provide density estimates in targets/hectare. The resulting data were gridded to provide the anomaly density images shown in Figures 17.

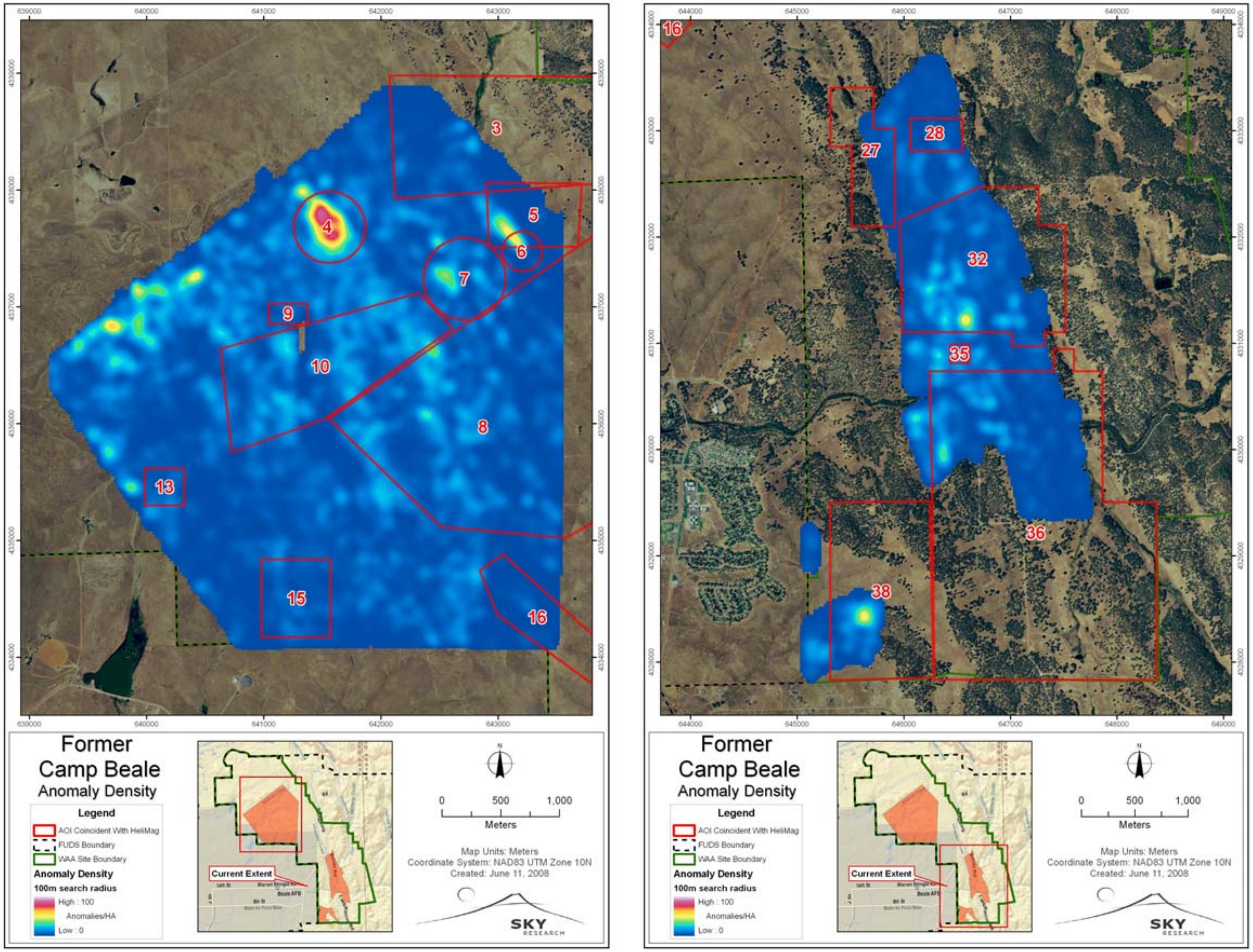


Figure 17. Final anomaly density maps.

4.3.3. Results By AOI

Because the HeliMag was not able to cover the entire WAA site, many of the revised AOIs supplied by the Program Office were not surveyed. In addition some of the AOIs were only partially surveyed and/or were partially masked by large amplitude geologic signal. Table 7 summarizes the conclusions that are supported by the HeliMag results. In this table, AOIs not covered at least in part by the HeliMag system are not listed. Furthermore the effects of geology were factored into the analysis/interpretation of the results for each AOI. In looking at the imagery it is clear to an experienced analyst that areas with extreme geologic responses provide little information regarding the presence of targets similar to our targets of interest. In the absence of an objective criterion to default or mask these areas (similar to the height above ground criterion used to default invalid data), the analyst noted these conditions and discounted the results for these areas.

Table 7. Summary of HeliMag Conclusions by AOI.

AOI	Notes (LiDAR)	HeliMag Observations
3		Very small % of area surveyed and not masked by geology - few sparsely distributed anomalies in these areas. Coverage too poor to support any conclusions.
4	Crater field	High anomaly density - typical of bombing target. Impact area is circular with an approximate 500 m diameter centered at East 641501 m, North 433732 m.
5		90% not surveyed and/or masked by geology - numerous small anomalies with density increasing towards AOI 6. The available data support the assertion of a bombing target in AOI 6.
6	Aiming circle with cratering	90% masked by geology - the remaining 10% has numerous small anomalies with moderate density. The available data support the assertion of a bombing target.
7	Crater field	Thick band of geology running NW-SE masks most of the area. Many small anomalies adjacent to geologic area near center of circle. Inconclusive results due to geology.
8		40% masked by geology - sparse to moderate density of anomalies. No obvious impact areas identified.
9	Potential craters and earthwork	Linear E-W feature (fence) running E-W through this area - very few anomalies. No obvious impact areas identified.
10		Numerous but sparsely distributed anomalies - isolated pockets of geology. No obvious impact areas identified.
13	Two closely spaced groups of potential craters	Linear feature (fence-like) runs NE - SW through center of area. Few, sparsely distributed small targets. No obvious impact areas identified.
15	Regularly spaced groups of potential craters	Linear feature (fence-like) runs NS through center of area. Numerous but sparsely distributed small targets. No obvious impact areas identified.

Table 7. Summary of HeliMag Conclusions by AOI (cont'd)

AOI	Notes (LiDAR)	HeliMag Observations
16	Part of Original FID 16	85% masked by geology. Very few anomalies in areas not masked. Inconclusive results due to geology/coverage.
27	Regular pattern of trenches, berms, earthwork	Only 25% of the area surveyed. Inconclusive results due to geology.
28	Regular berms	75% coverage, significant geology in western 1/3 of area. Two linear fence-like features (E-W and NE-SW). No evidence of impact areas found.
32	Many potential firing points	Eastern 1/3 not surveyed and the remaining coverage is sparse in some areas due to topography/vegetation. A band of geologic response runs N-S through the center of the area. Although no obvious impact areas were found, the results are inconclusive due to geology and coverage.
35	Potential craters along old road	Linear N-S feature. Moderate geology, but no obvious impact area identified.
36	Scattered potential craters no obvious pattern	Southern 1/3 not surveyed and the remaining coverage is sparse in some areas due to topography/vegetation. A band of geologic response runs N-S through the center of the covered area. Although no obvious impact areas were found, the results are inconclusive due to geology and coverage.
38	Part of Original FID 13	Less than 20% coverage – results inconclusive due to coverage and geology.

4.3.4. Density Results Discussion

The geologic response can both artificially increase the number of detected targets as well as decrease the number of detected targets. In regions with moderate geologic response, there can be a significant number of anomalies that appear to have the same character (i.e., similar in amplitude, shape and spatial extent) as we would expect from a discrete, metallic, UXO-like source. Accordingly the density model for these areas will be artificially elevated. Conversely, in regions with extremely challenging geology, the geologic response will mask anomalies with the relatively small amplitudes of our targets of interest. In this case the anomaly density data will be artificially reduced.

In an effort to mitigate these effects attempts were made to both reduce the geologic signal through the use of a directional filter and refine the target list based upon features derived through dipole fit analyses of the anomalies. These processes were applied to subsets of the North area to determine their effectiveness. They were not performed on the entire dataset, nor were the results used in the site by site synopses or images provided above.

4.3.4.1. Directional Filter Results

A recursive 1D filter was applied to two subsets of the North area. Although this filter is directional, it is applied to the geo-referenced data, not to gridded or interpolated data. This process is summarized as follows:

- The user estimates the direction of the geological strike
  - The algorithm could be applied in many direction as required
- A 1D recursive demedian is applied along the user specified direction
  - Points are selected that lie between two parallel lines separated by 1 m (e.g., see Figure 18)
  - Points within these two parallel lines are binned at 0.1 m distance along the line to create a 1D profile
  - The background of the 1D profile is estimated using a recursive demedian filter
  - The background is interpolated to each point within the parallel lines and removed
  - This process is repeated until the entire area has been filtered

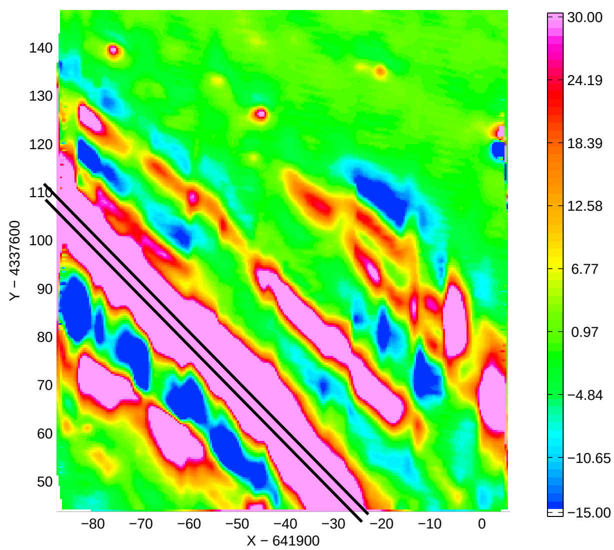


Figure 18. Directional 1D geology filter test area.

The results of this filter are encouraging for areas with moderate geology (Figure 19).

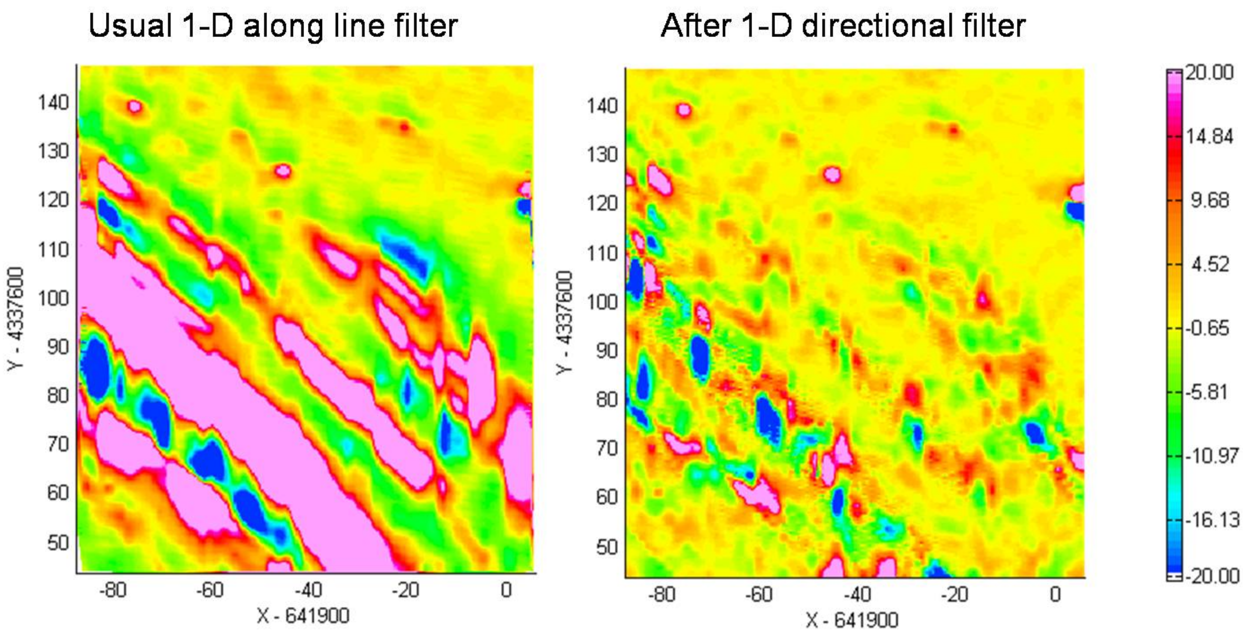


Figure 19. Directional 1D filter test results.

However, when applied to areas with extremely challenging geology (Figure 20) significant, high frequency, high amplitude features remain. These features will continue to skew the anomaly density results.

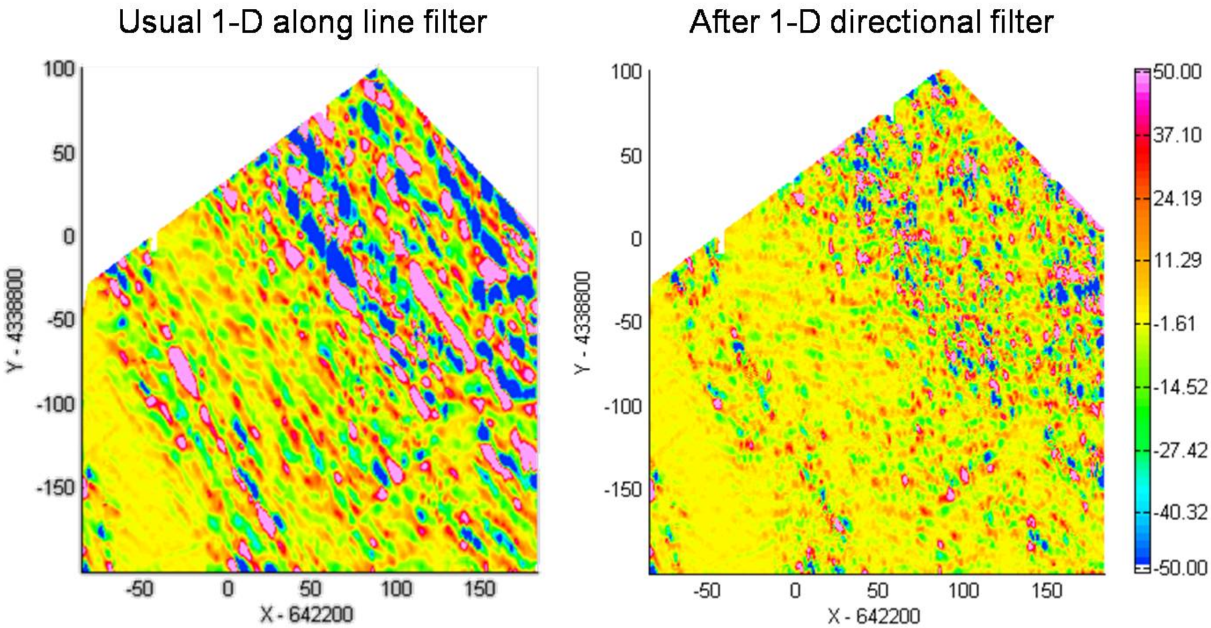


Figure 20. Directional 1D filter results for extremely challenging geology.

4.3.4.2. Refined Target List Results

As mentioned above, in areas with moderate geology a significant number of detected anomalies are due to geologic sources. When the geology is spatially variable, the final anomaly density images will be distorted by the presence of these additional targets. In an effort to remove this effect we attempt to refine our target list by culling the selected targets based upon features derived through a dipole fit analysis of each target.

The dipole fit analysis described in Section 4.1 provides recovered dipole moment features that are used to classify each target as described in Billings 2004. Briefly explained, the recovered dipole moment is plotted relative to the Earth's field, and compared to the theoretical dipole moments of candidate ordnance items. Because the dipole moment of an individual ordnance item will vary with its orientation relative to the Earth's field, the moments of the candidate ordnance are plotted as feasibility curves (rather than a single representative point). The normalized distance of a given derived moment from these feasibility curves is used to assess the likelihood of the target in question potentially being one of the candidate ordnances.

In this test we use three candidate ordnances in our classification routine: a 155 mm projectile, a 4.2" mortar, and an 81 mm mortar (Figure 21). These items were used to represent large, medium, and small ordnance. Very few anomalies fit the 81 mm so it was removed from the analysis.

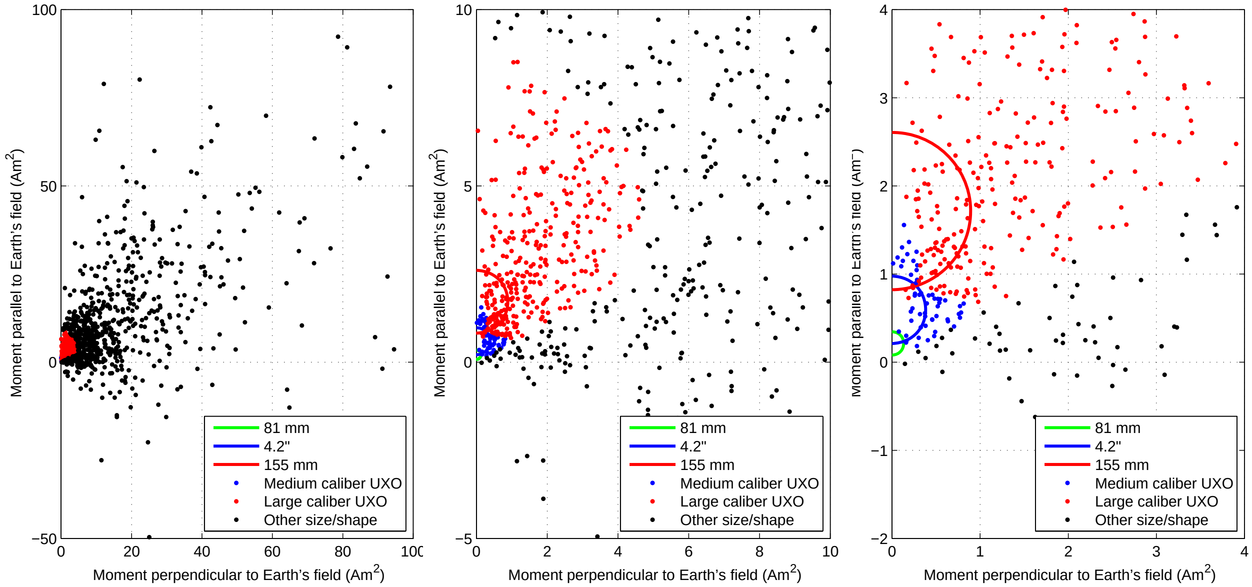


Figure 21. Recovered moments for classified anomalies presented at three different scales.

Based upon these results, the anomalies were classified as 'No-Fits' (the dipole-fit routine did not provide a high quality fit result), Medium/Large UXO-like, and Non-UXO like. In Figure 22 we show the initial 'non-refined' density results, and the densities of each of the classification categories. At the center of the impact area, there is a high concentration of no-fits. This is expected because of the overlapping magnetic signatures. The maps of TMF data and anomaly density for each AOI are provided in Appendix A. Appendix B provides full-sized versions of the four panels illustrated in Figure 22.

Unlike dipole fit modeling for remediation applications this dipole modeling was applied in a less rigorous, automated manner (i.e., no effort was made to refine the anomaly boundaries and remove overlapping signatures). Thus the results for individual targets are not trustworthy from a dig prioritization perspective, but the aggregate of the results are useful and valid from a characterization / anomaly density perspective.

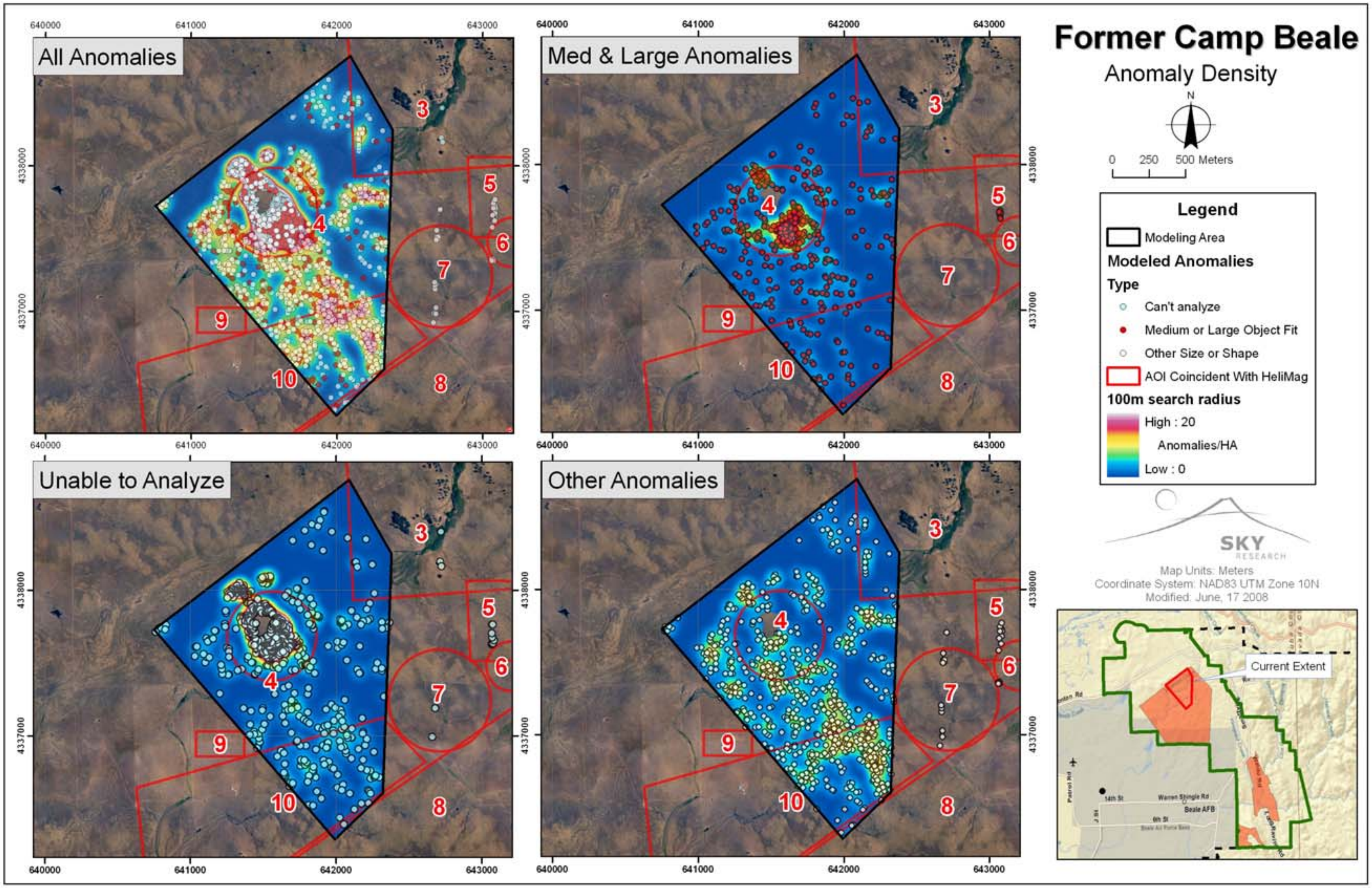


Figure 22. 'Refined' density results for a subset of the Camp Beale HeliMag survey area. The classes shown are (clockwise starting at the top left panel): all anomalies, medium/large UXO-like anomalies, other (i.e., non-UXO-like) anomalies, and anomalies that did not fit a dipole.

5. COST ASSESSMENT

5.1. Cost Reporting

Cost information associated with the demonstration of all airborne technology, as well as associated activities, was tracked and documented before, during, and after this demonstration to provide a basis for determining the operational costs associated with this technology. Table 8 contains the cost elements that were tracked and documented for the demonstration.

The costs documented include both operational and capital costs associated with system design and construction; salary and travel costs for support staff; subcontract costs associated with airborne services, support personnel, and leased equipment; and costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration.

An additional cost category reflected in Table 8 that is not typical of WAA projects is that of providing a field biologist on-site during survey operations. The presence of a biologist was required by California state and federal wildlife agencies during survey activities to insure that no sensitive, threatened, or endangered wildlife species or habitats were negatively impacted from HeliMag operations. The total project cost reflects this additional category, but it is not included in the calculation of total technology cost or cost per acre to utilize HeliMag in WAA.

5.2. Cost Analysis

The single largest cost element for an airborne survey is the cost of aircraft airtime. In addition, mobilization costs for the helicopter can be significant. Generally, mobilization cost is a function of distance from the home base for the aircraft, equipment, and personnel. Because the helicopter was mobilized a relatively short distance (from Reno, NV to Yuba City CA) the costs for mobilization for this demonstration were significantly less than would have been encountered for a demonstration site further away. Data processing and analysis functions made up the bulk of the remaining costs associated with the technical performance of this project.

Project management and reporting were a significant cost for this demonstration, as the project was conducted under the WAA pilot program and required more meetings, travel, and reporting than would generally be expected for a production level survey.

Costs associated with validation were not considered in the cost analysis, as the validation was conducted as part of the WAA pilot program.

Table 8. Cost Tracking

Cost Category	Sub Category	Details	Costs ($)
Start-up Costs	**Pre-Deployment and Planning**	**Includes planning, contracting, site visit, and site inspection**	**$14,146**
	Mobilization	**Personnel mobilization, equipment mobilization, and transportation, boom assembly**	**$18,862**
Operating Costs	**Helicopter Survey**	**Data acquisition and associated tasks, including helicopter rental/operation time**	**$292,356**
Demobilization	**Demobilization**	**Demobilization, packing, calibration line removal**	**$9,431**
Data Processing and Analysis	**Data Processing**	**Initial and secondary processing of data**	**$42,439**
	Data Analysis	**Analysis of airborne magnetometry datasets**	**$51,869**
Management	**Management and Reporting**	**Project related management, reporting and contracting**	**$42,439**
TOTAL COSTS			
		Total Project Cost	
		Total Technology Cost	**$471,542**
		Acres Surveyed	**4,814**
		Unit Cost	**$97.95/acre**

6. IMPLEMENTATION ISSUES

6.1. Regulatory and End User Issues

The ESTCP Program Office has established a WAA pilot program Advisory Group to facilitate interactions with the regulatory community and potential end-users of this technology. Members of the Advisory Group include representatives of the US EPA, State regulators, Corps of Engineers officials, and representatives from the services. ESTCP staff has worked with the Advisory Group to define goals for the WAA pilot program and develop Project Quality Objectives.

On a general level, there will be a number of issues to be overcome to allow implementation of WAA beyond the pilot program. Most central is the change in mindset that will be required if the goals of WAA extend from delineating target areas to collecting data that are useful in making decisions about areas where there is not indication of munitions use. A main challenge of the WAA pilot program is to collect sufficient data and perform sufficient evaluation that the applicability of these technologies to uncontaminated land and their limitations are well understood and documents. Similarly, demonstrating that WAA data can be used to provide information on target areas regarding boundaries, density and types of munitions to be used for prioritization, cost estimation and planning will require that the error and uncertainties in these parameters are well documented in the program.

The demonstration at Camp Beale served to reveal some of the challenges and limitations of using this technology under less than ideal conditions. Specifically, the variable geologic regimes at Camp Beale resulted in obvious distortions of the anomaly density calculations. Depending upon the severity and character of the geologic response, the anomaly density results could be skewed in either direction. This made it difficult to rely on automated, objective analyses for both anomaly selection and interpretation of the results.

In some cases (e.g., AOI 4) the results provided strong, unambiguous evidence of the existence of an impact area (supporting the CSM assumptions) While in other areas (e.g., AOI 5/6) this evidence is somewhat dependent upon the judgment of the analyst due to the complicating nature of the spatial variability of the geologic response. Finally in other areas it was obvious that the data do not support any conclusions at all. In these areas the data should be discounted in a manner similar to the way data collected over a predefined altitude threshold are handled. Unfortunately an objective criterion such as altitude is not available to use for a keep/default decision.

A couple of processing techniques (Directional 1D filtering of the magnetic data, and analysis/classification of targets) designed to mitigate the effects of geology were shown to have promise, particularly in areas with moderate geologic response. The application of this technology in areas with extreme geologic response is not valid at this time.

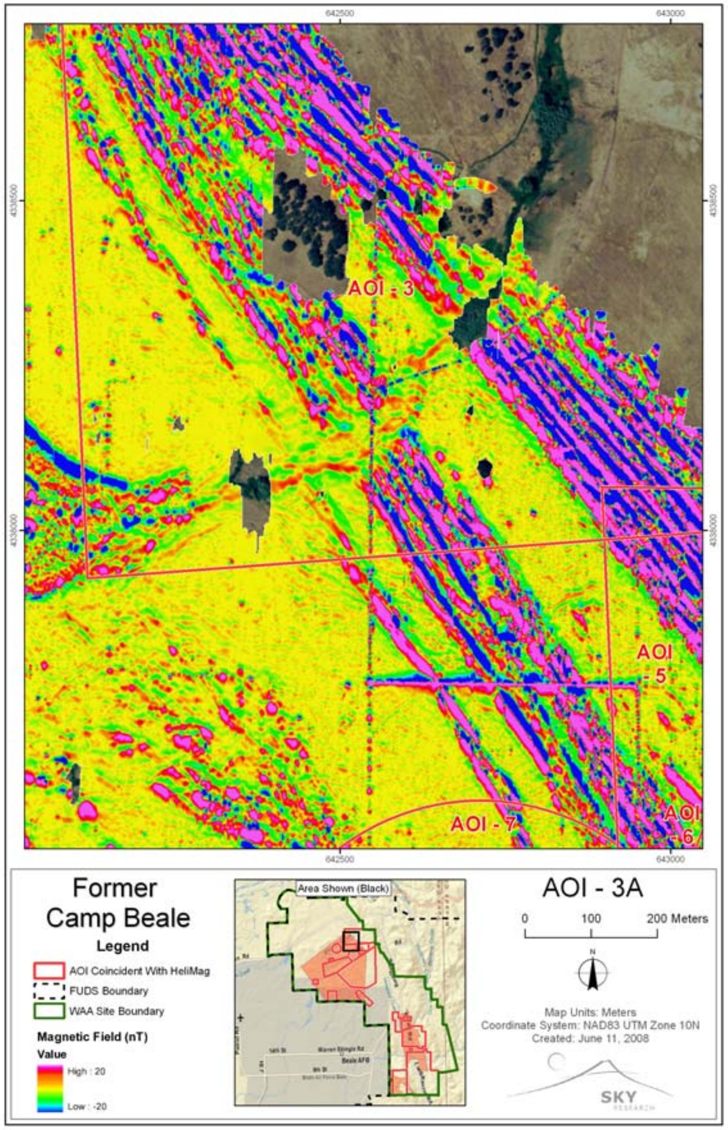
7. REFERENCES

Billings, S. D., 2004. Discrimination and classification of buried unexploded ordnance using magnetometry: *IEEE Transactions of Geoscience and Remote Sensing*, 42, 1242-1251.

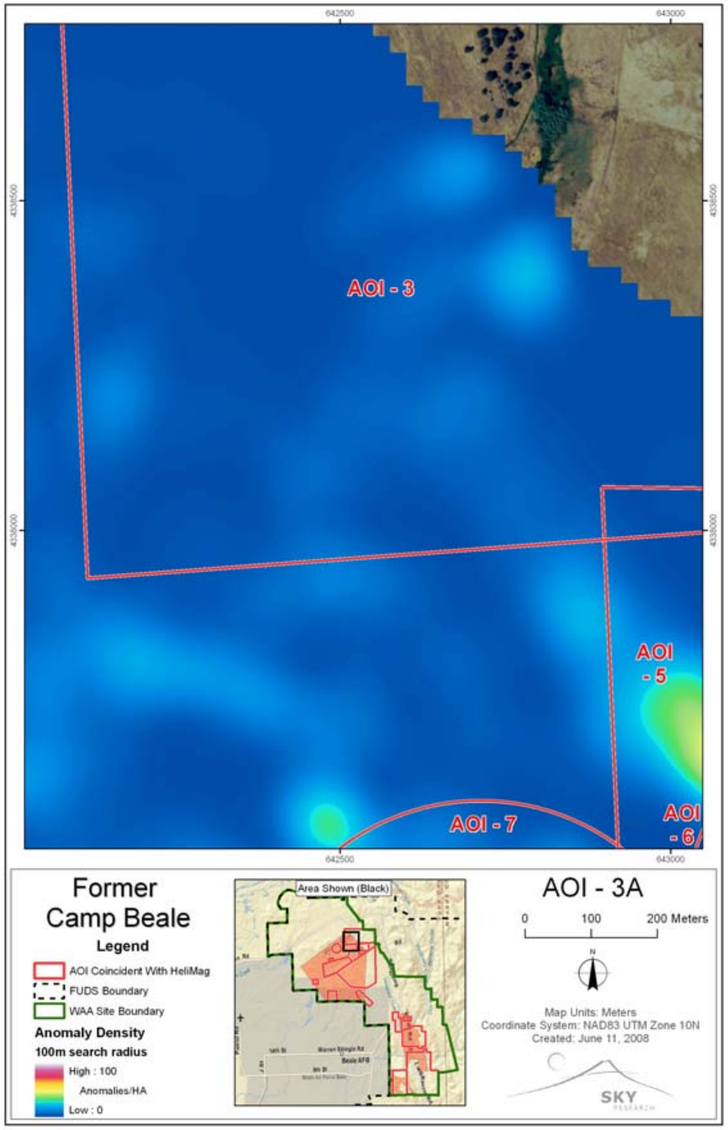
M. Tuley, and E. Dieguez, 2005. “Analysis of Airborne Magnetometer Data from Tests at Isleta Pueblo, New Mexico,” IDA Document D-3035.

U.S. Army Corps of Engineers – Huntsville Division, 1993. “Archive Search Report Findings: Camp Beale and Beale Air Force Base,” Defense Environmental Restoration Program for Formerly Used Defense Sites, Sites Nos. J09CA076600 & J09CA013600.

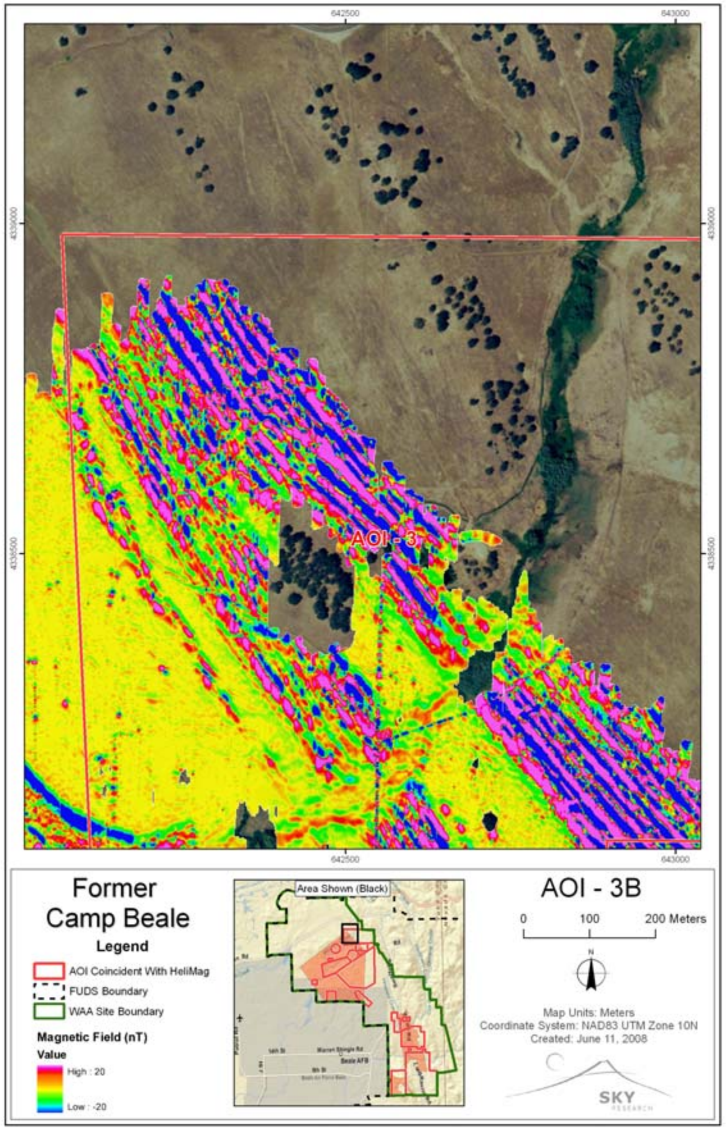
APPENDIX A – TOTAL FIELD MAGNETOMETRY AND ANOMALY DENSITY MAPS BY AOI



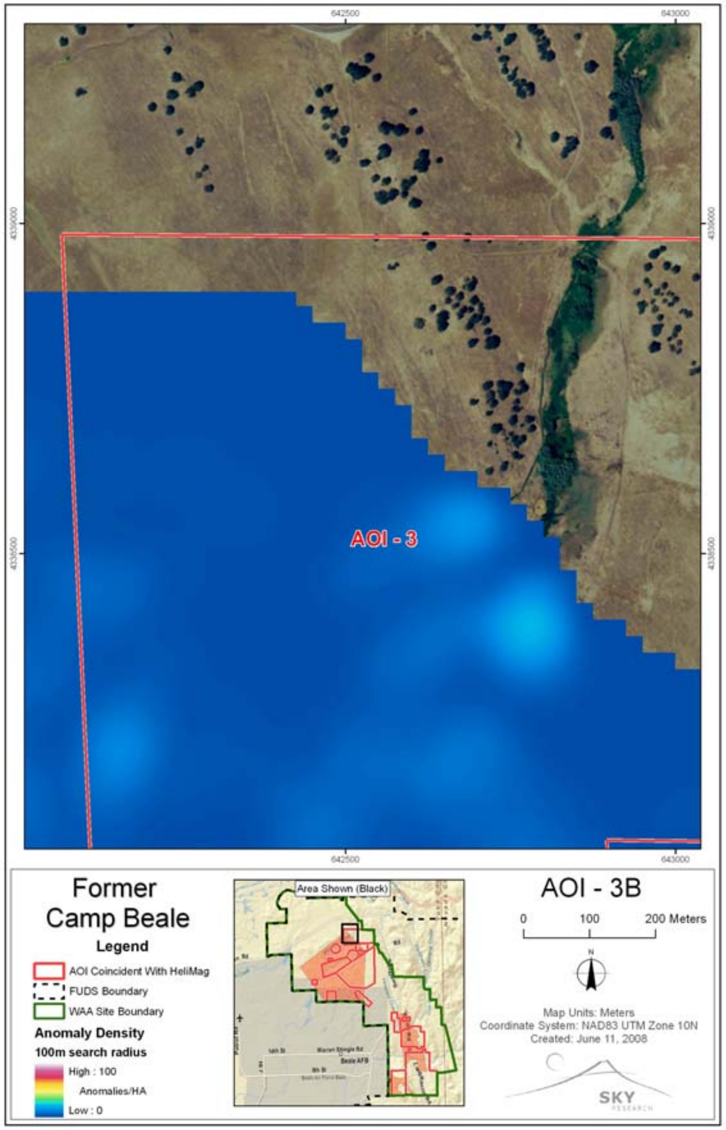
AOI - 3
AOI - 5
AOI - 7
AOI - 6
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 3A
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY



AOI - 3
AOI - 5
AOI - 7
AOI - 6
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 3A
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY



AOI - 3
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 3B
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY



AOI - 3
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 3B
0
100
200 Meters
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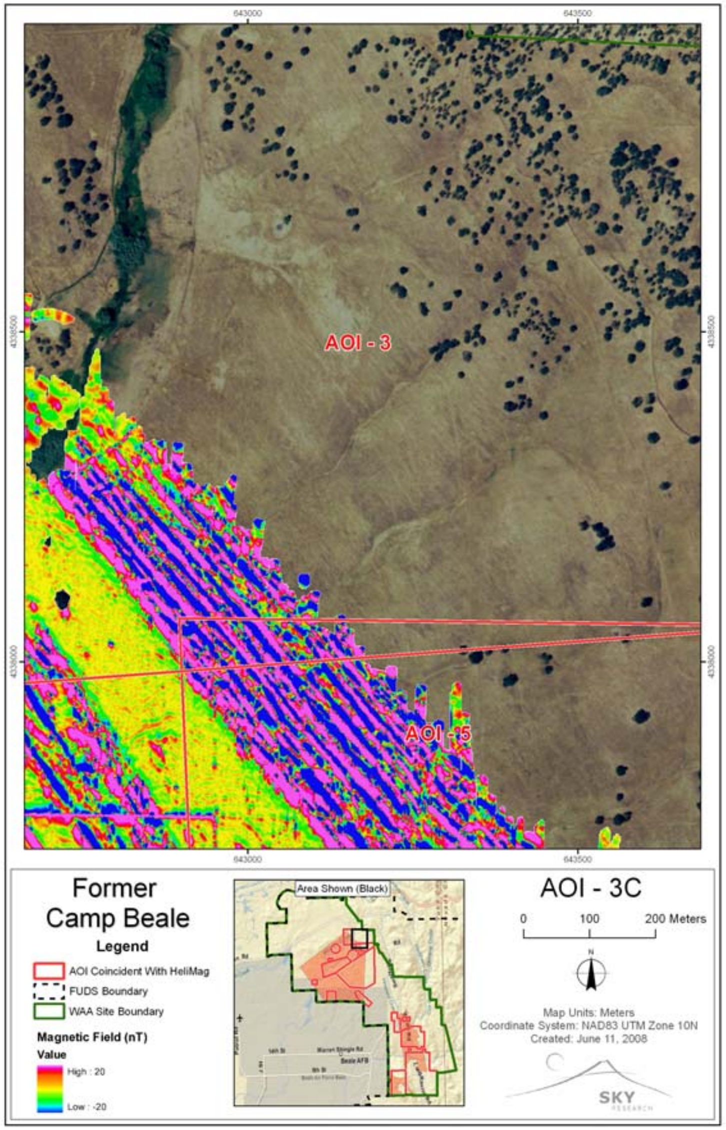
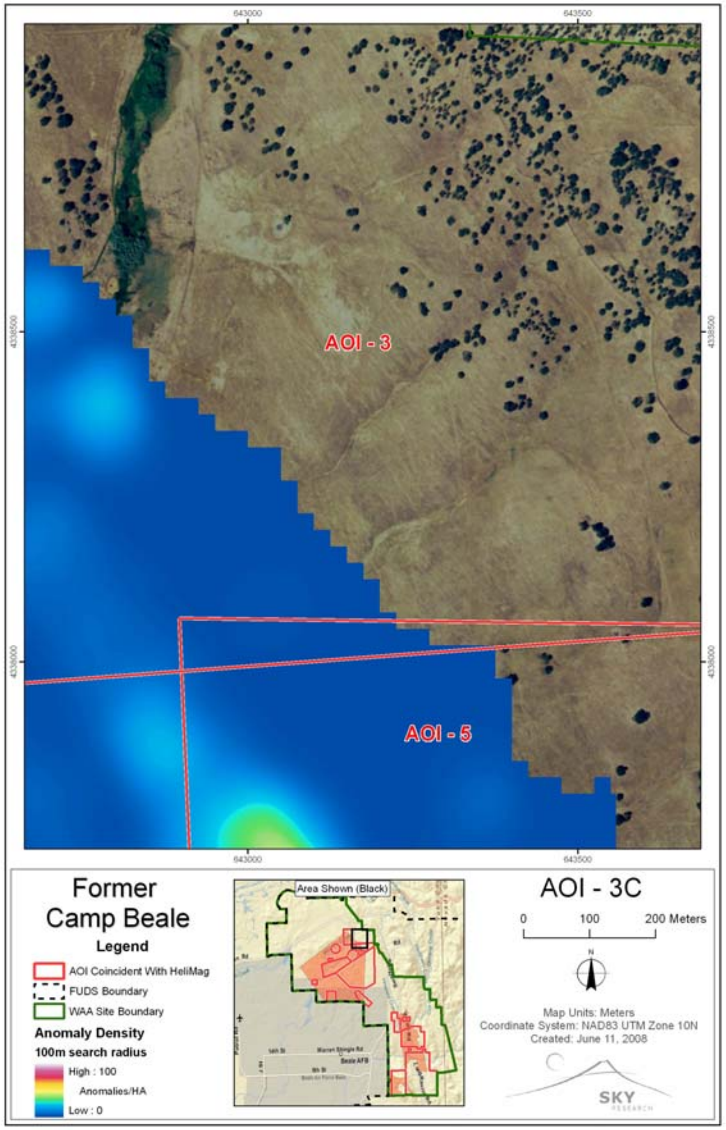

AOI - 3
AOI - 5
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 3C
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY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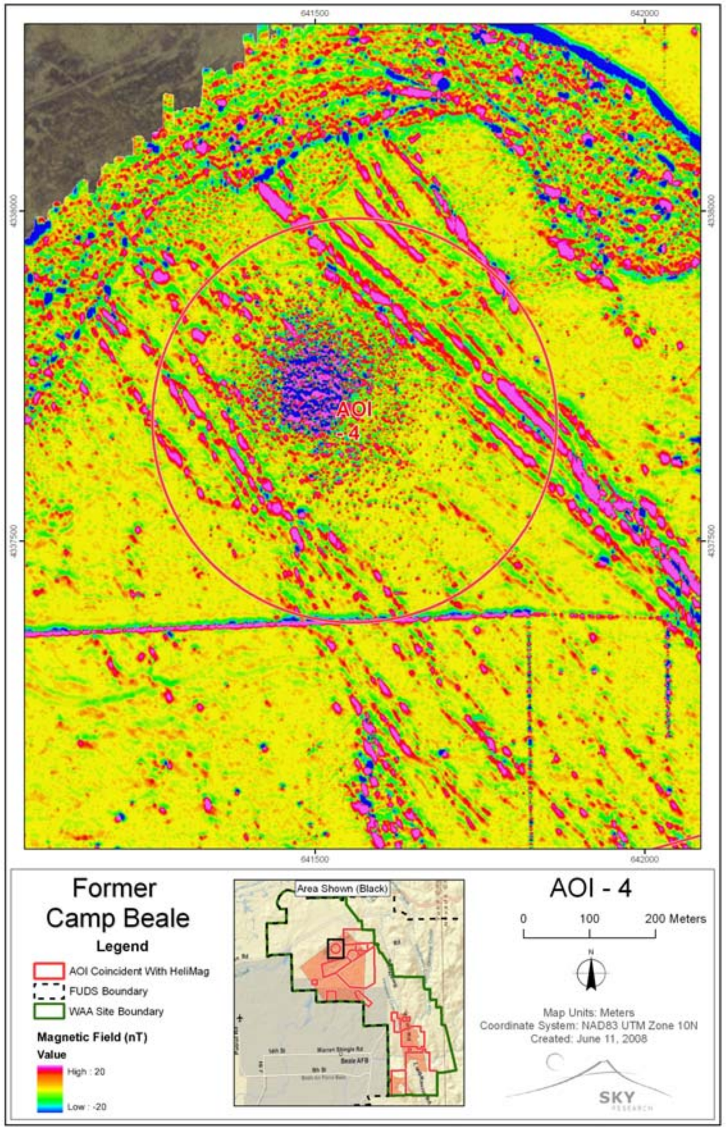
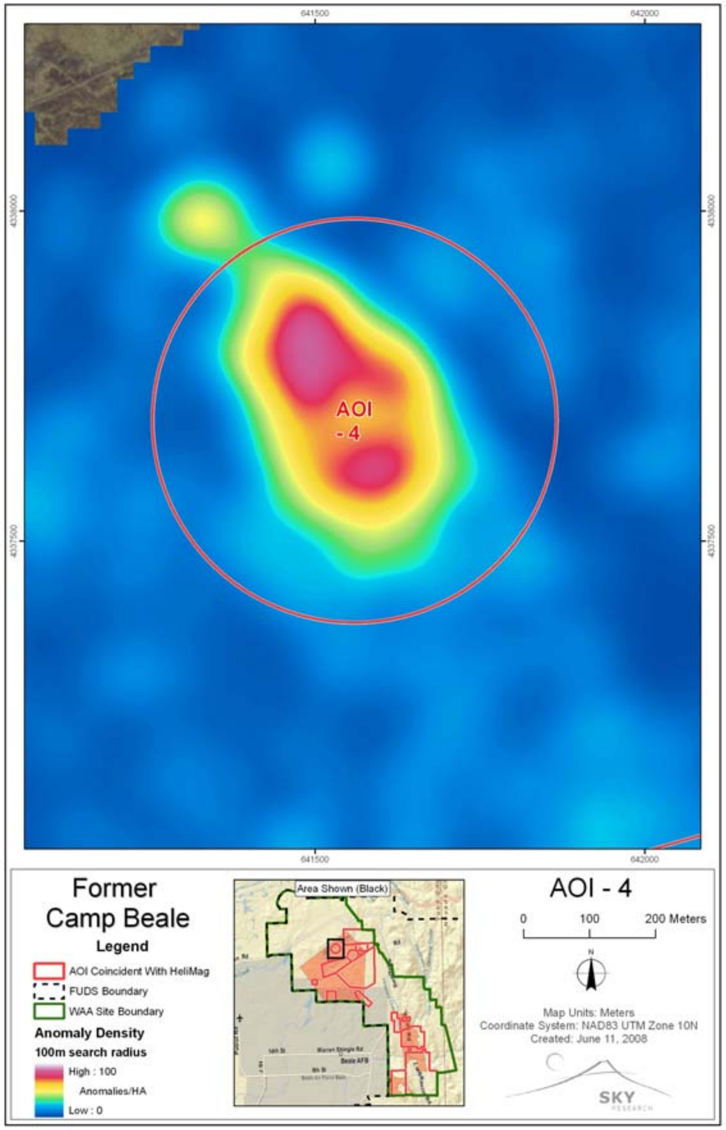
AOI - 5
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 3C
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY


641500
642000
AOI - 4
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 4
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY


641500
642000
AOI - 4
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 4
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
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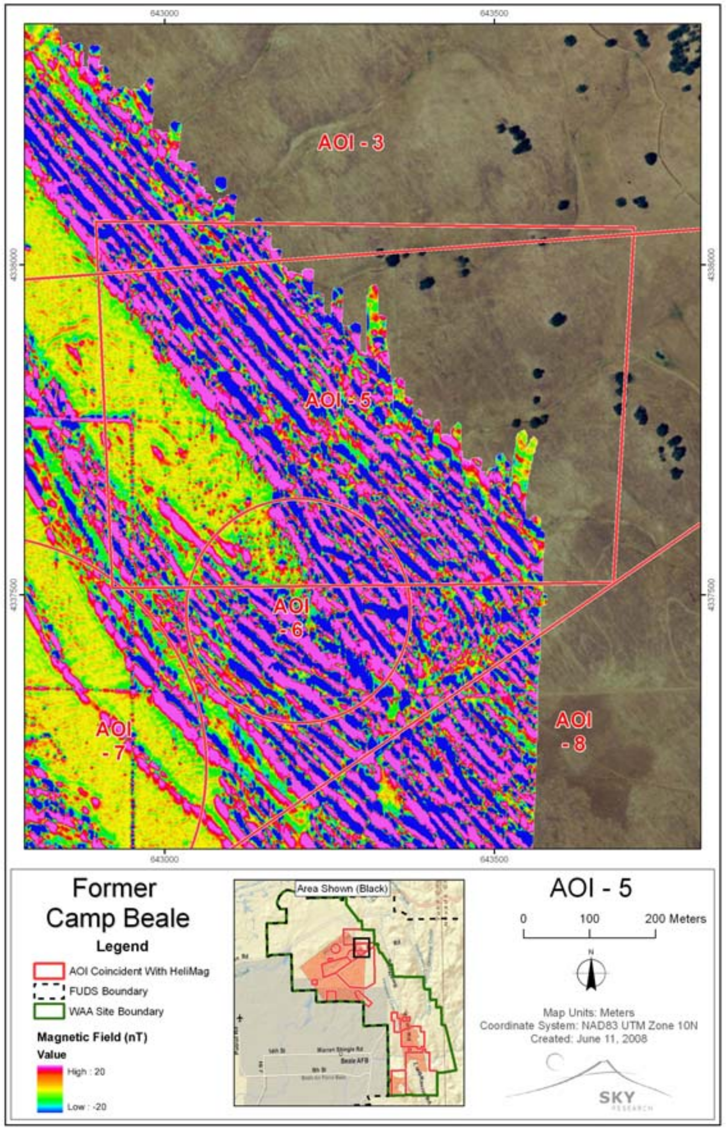

AOI - 3
AOI - 5
AOI - 6
AOI - 7
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 5
0
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200 Meters
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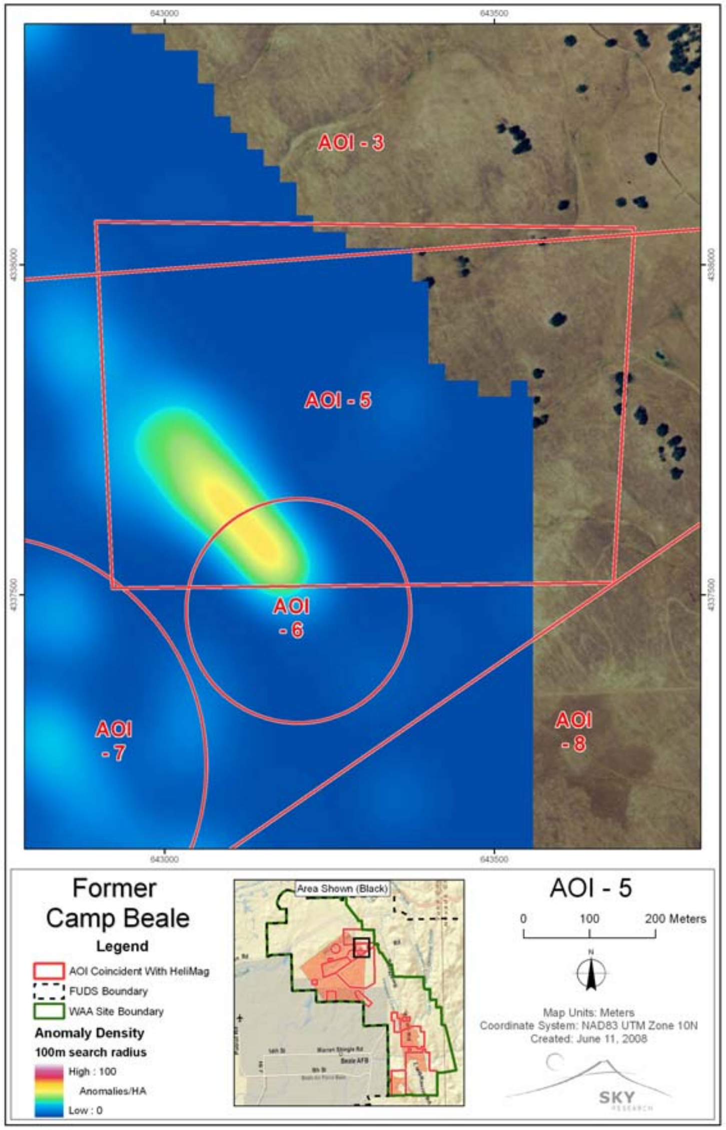

AOI - 3
AOI - 5
AOI - 6
AOI - 7
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
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200 Meters
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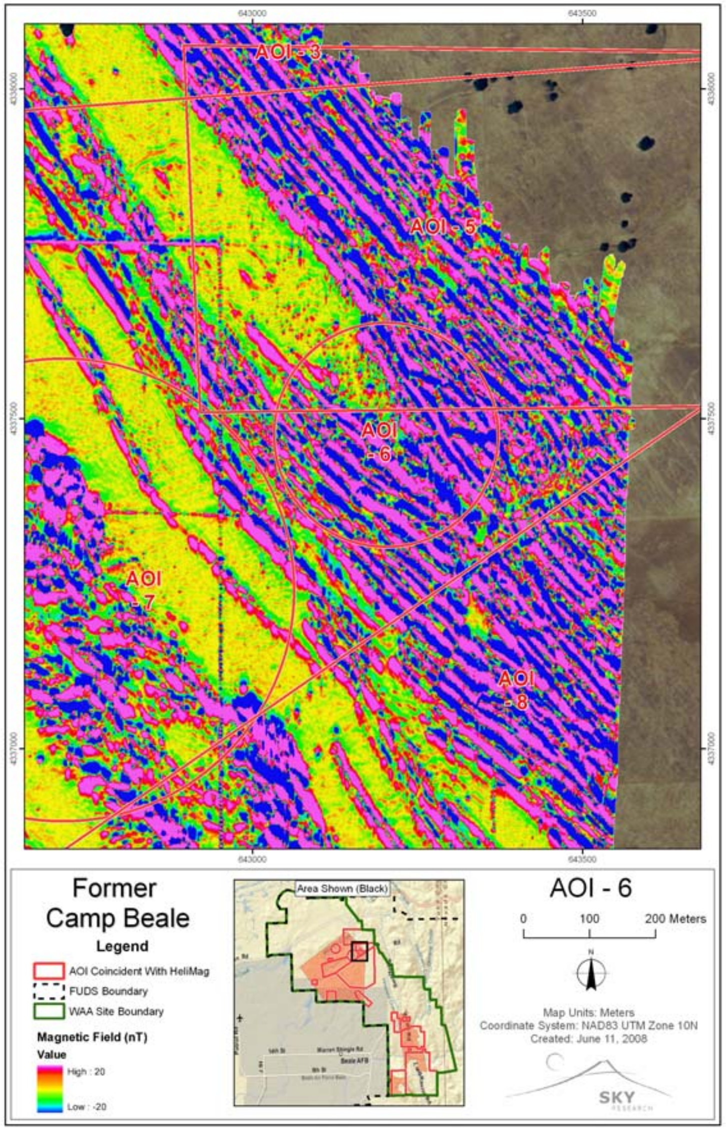
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AOI - 5
AOI - 6
AOI - 7
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
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200 Meters
Map Units: Meters
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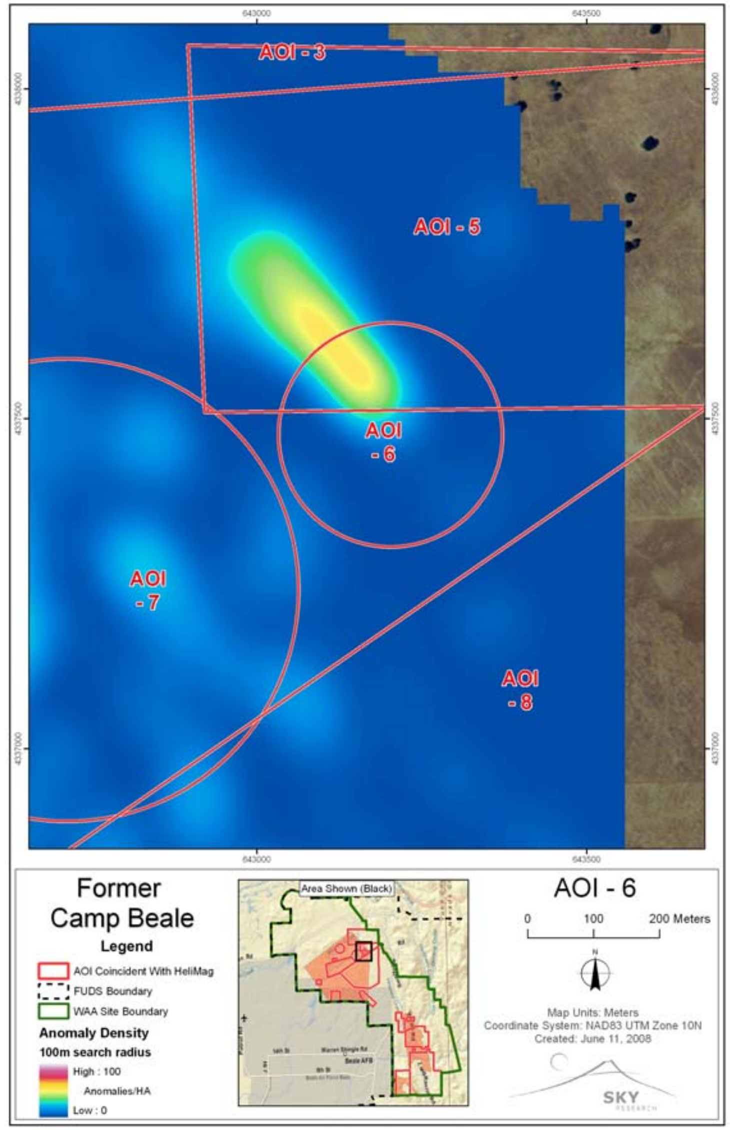
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AOI - 5
AOI - 6
AOI - 7
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
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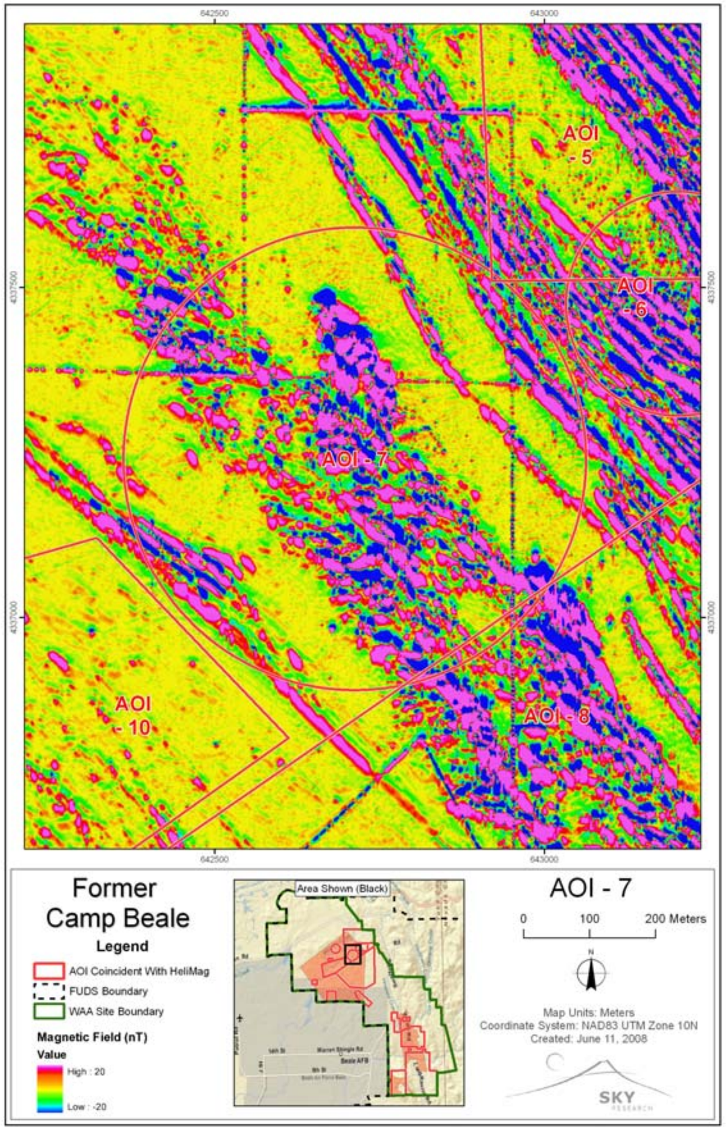
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4337000
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AOI - 6
AOI - 7
AOI - 8
AOI - 10
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
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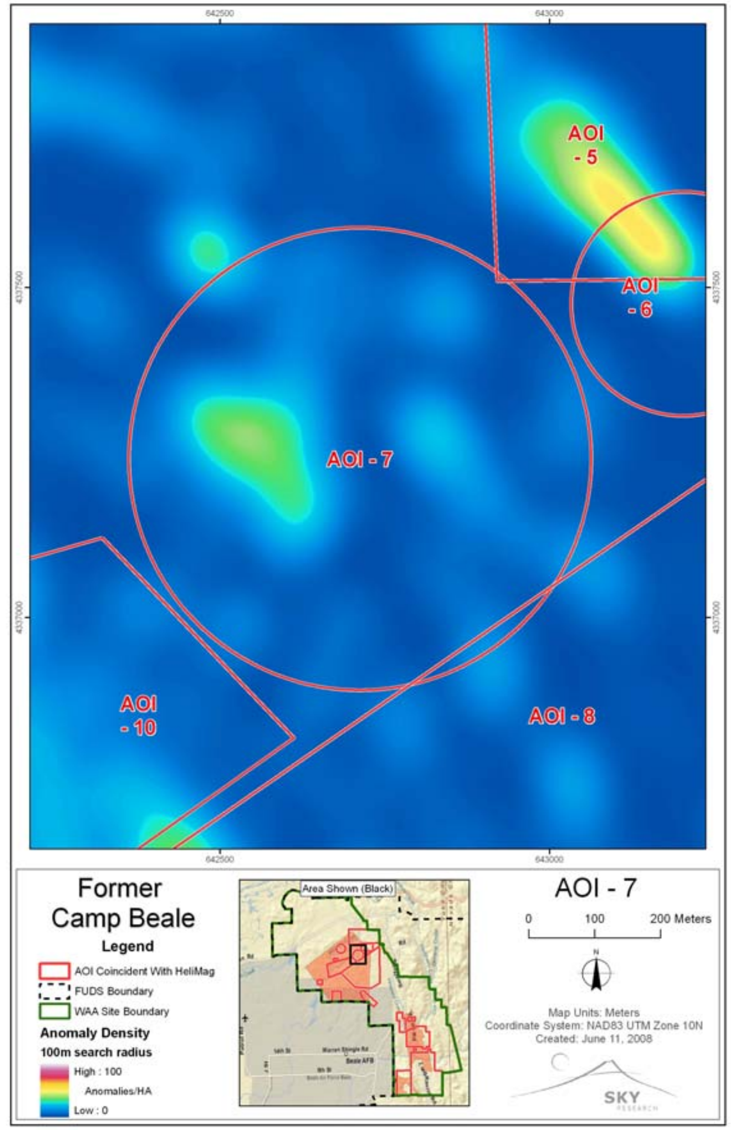
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AOI - 5
AOI - 6
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AOI - 8
AOI - 10
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
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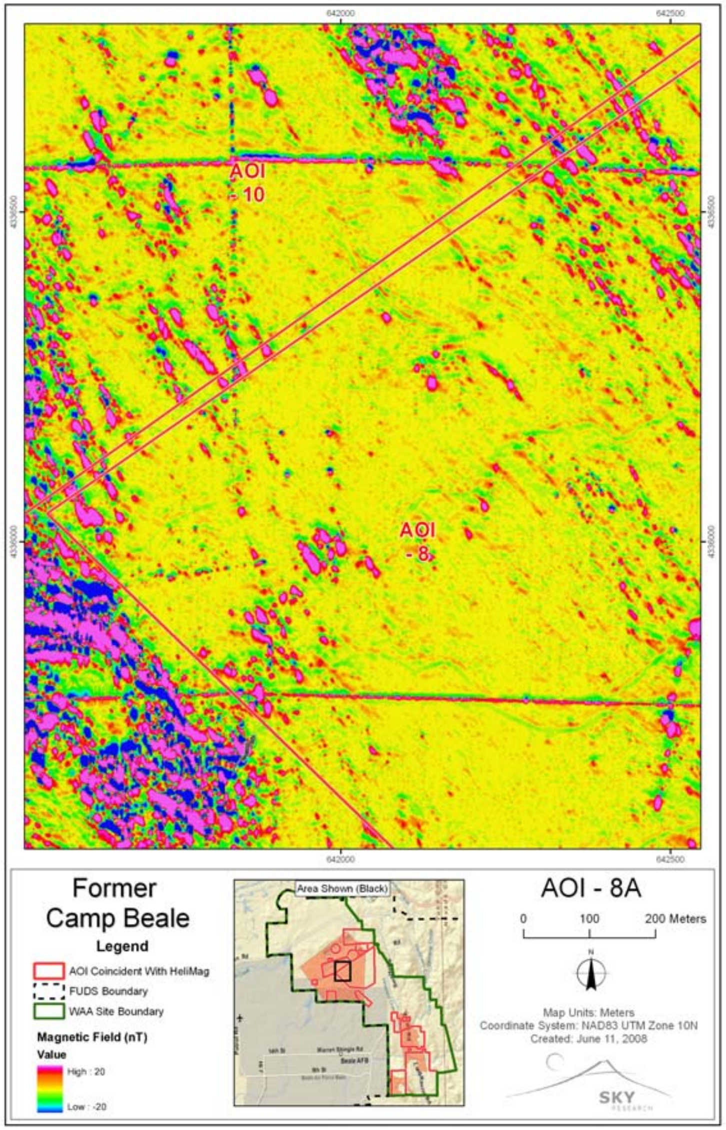
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Former Camp Beale
Legend
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FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
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Low : -20
Area Shown (Black)
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Map Units: Meters
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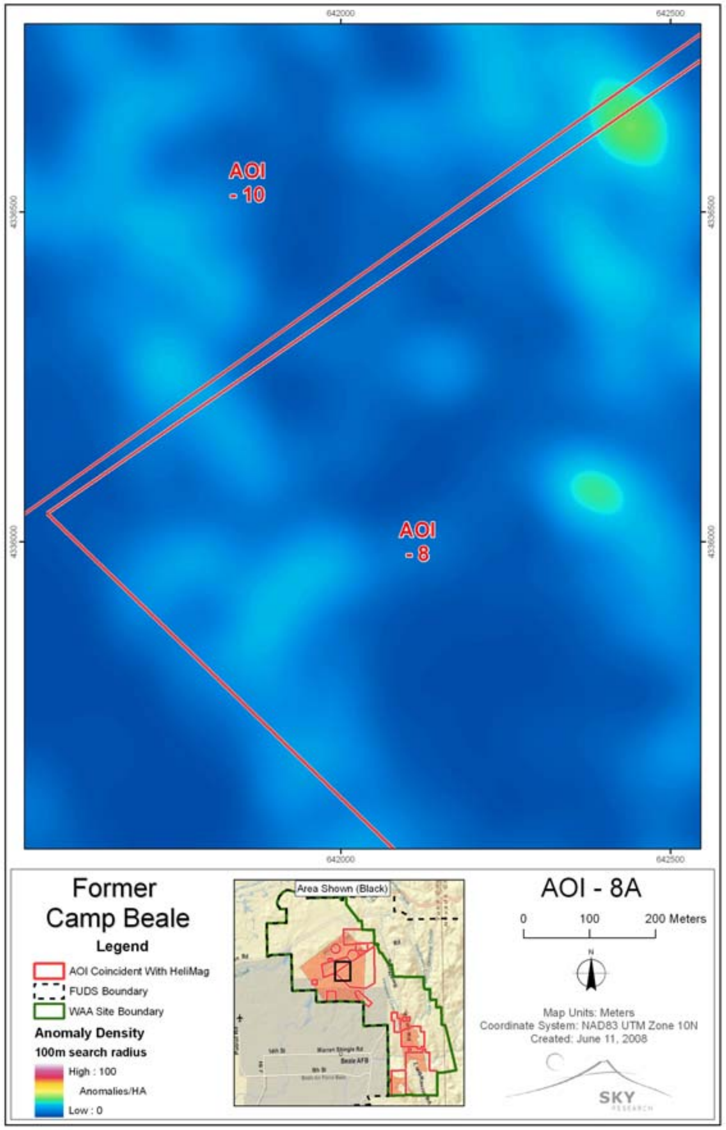
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Former Camp Beale
Legend
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FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
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Anomalies/HA
Low : 0
Area Shown (Black)
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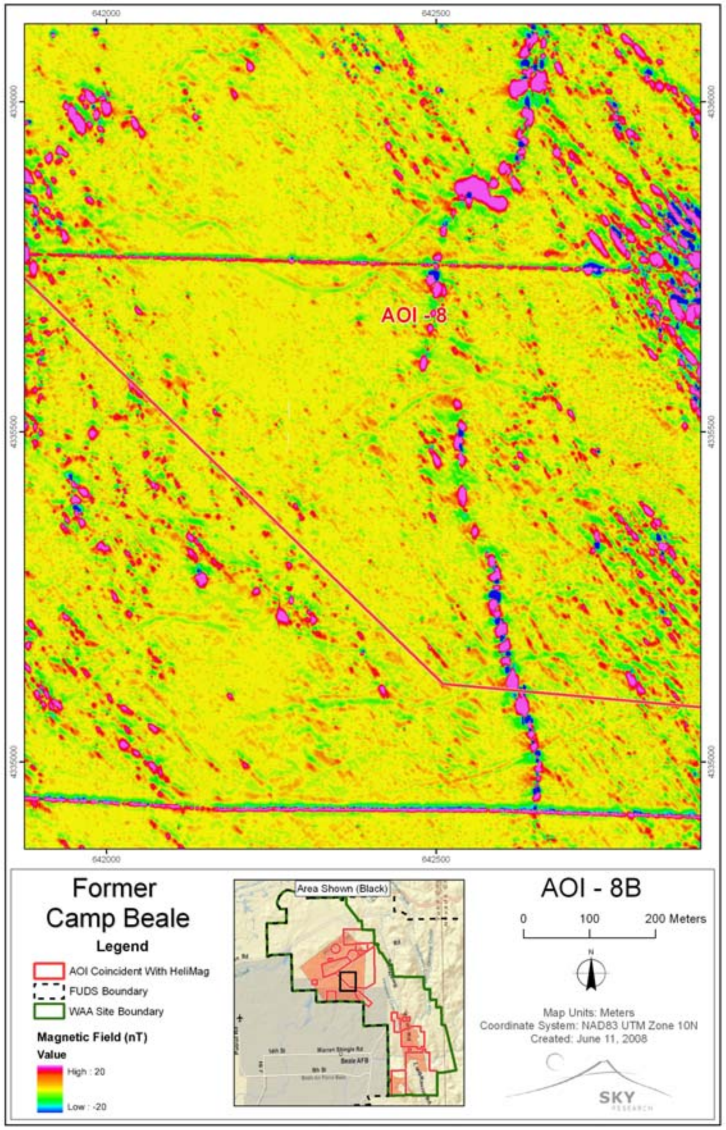
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Legend
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WAA Site Boundary
Magnetic Field (nT)
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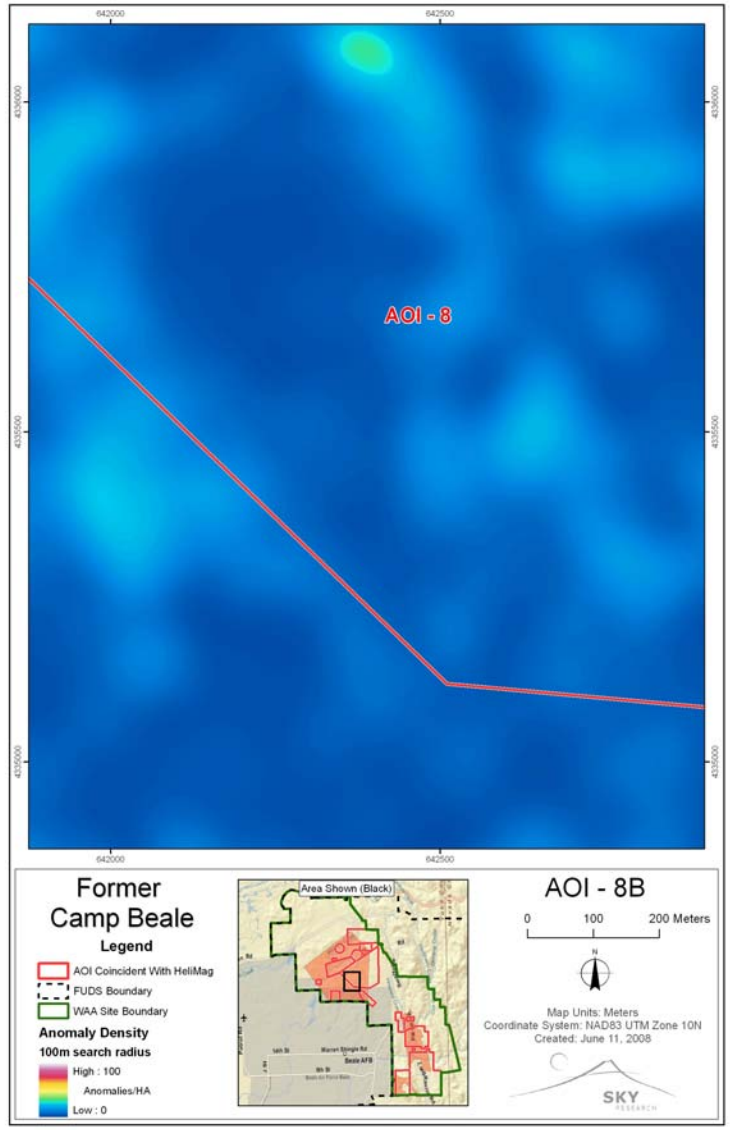
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WAA Site Boundary
Anomaly Density
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Anomalies/HA
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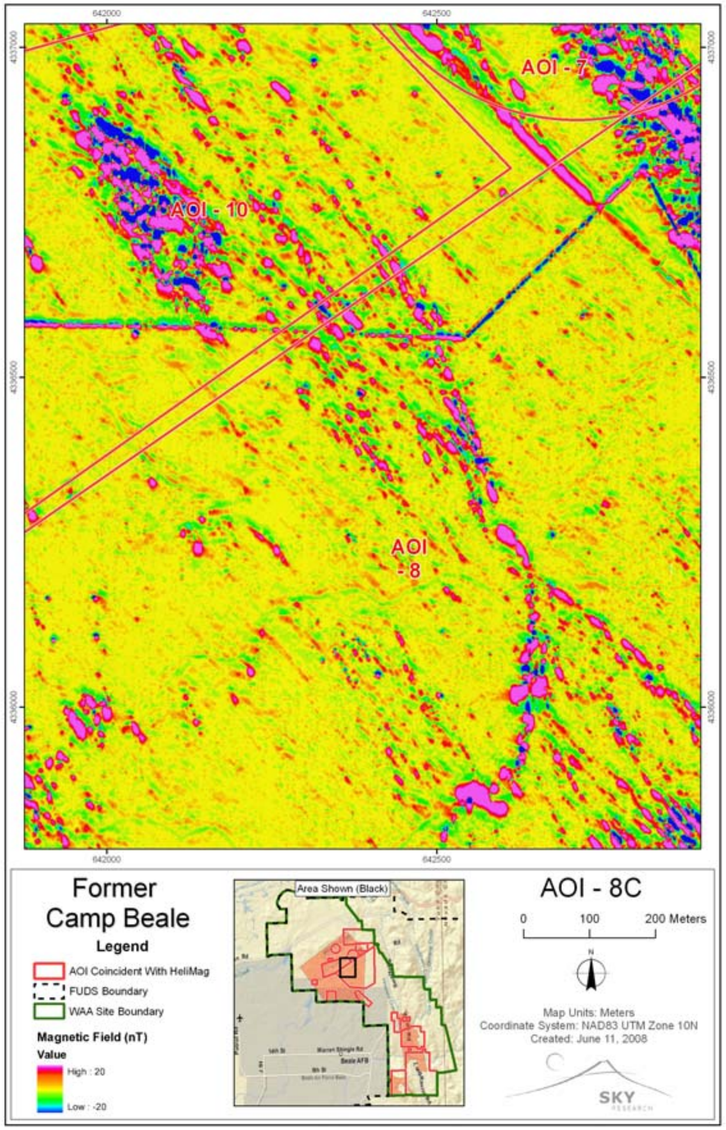

AOI - 7
AOI - 10
AOI - 8
Former Camp Beale
Legend
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FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
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200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
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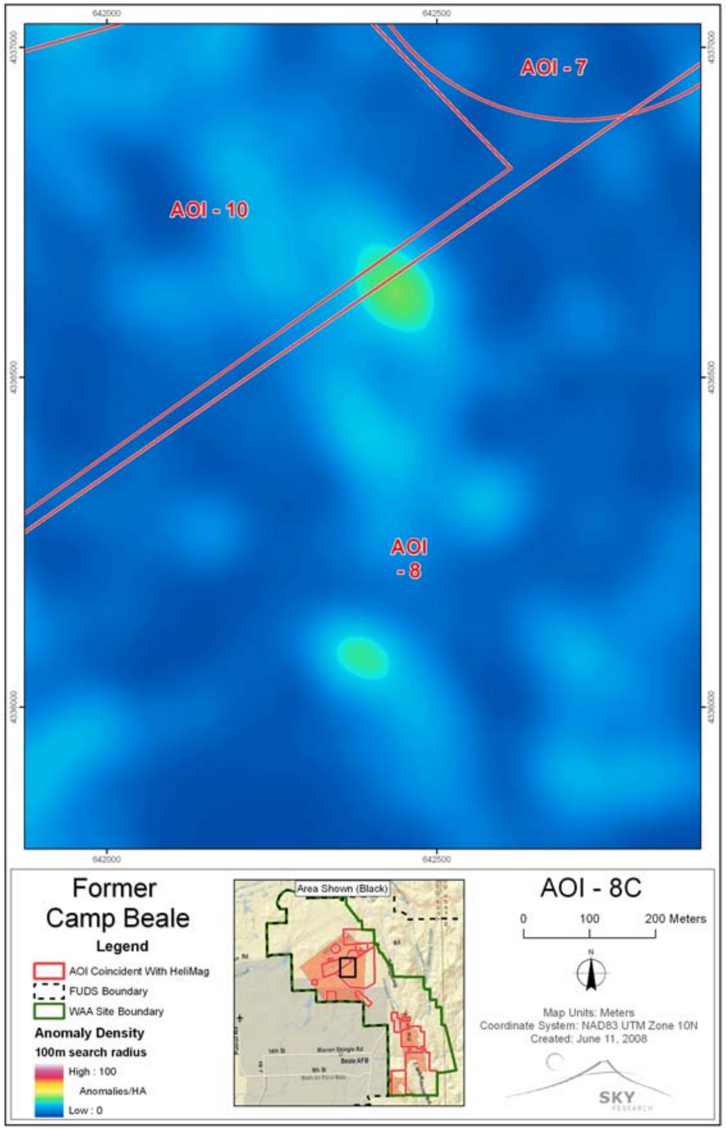

AOI - 7
AOI - 10
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 8C
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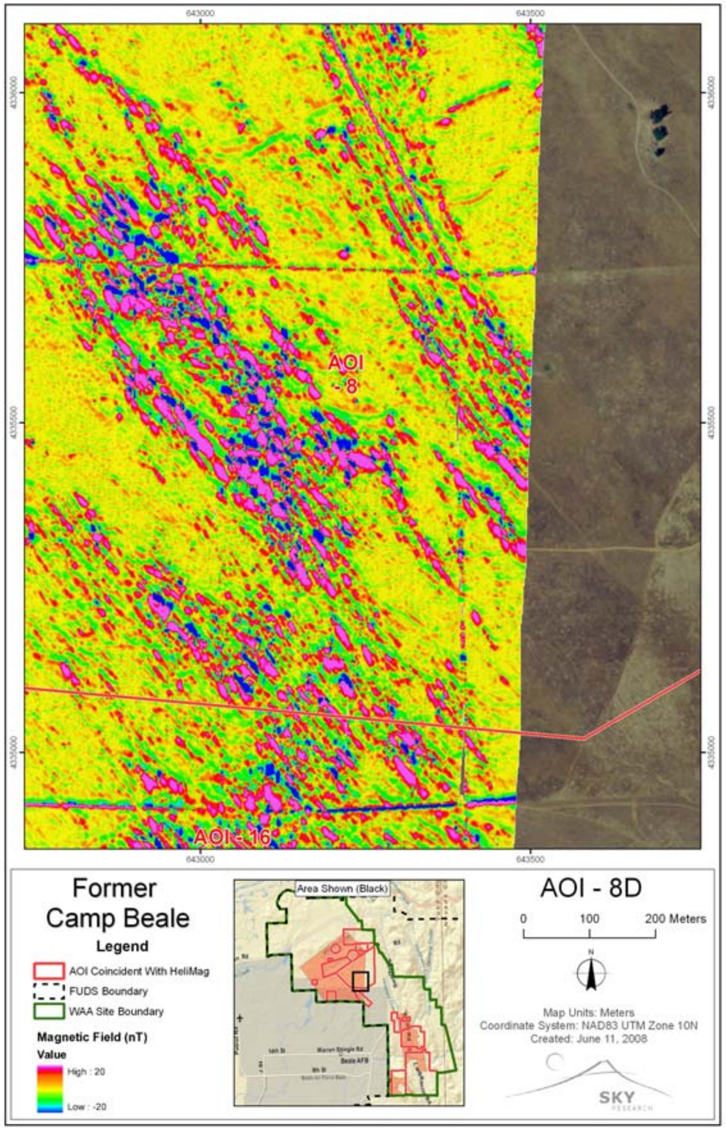
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY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AOI - 16
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
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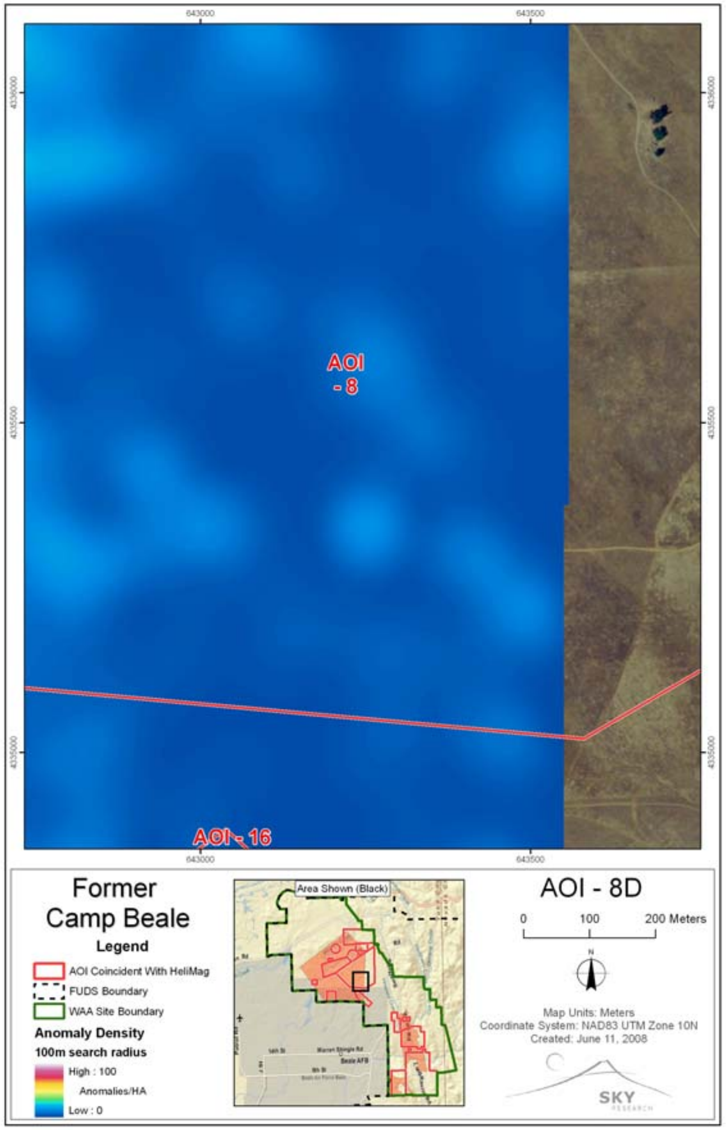
Area Shown (Black)
AOI - 8D
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY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AOI - 16
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
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Created: June 11, 2008
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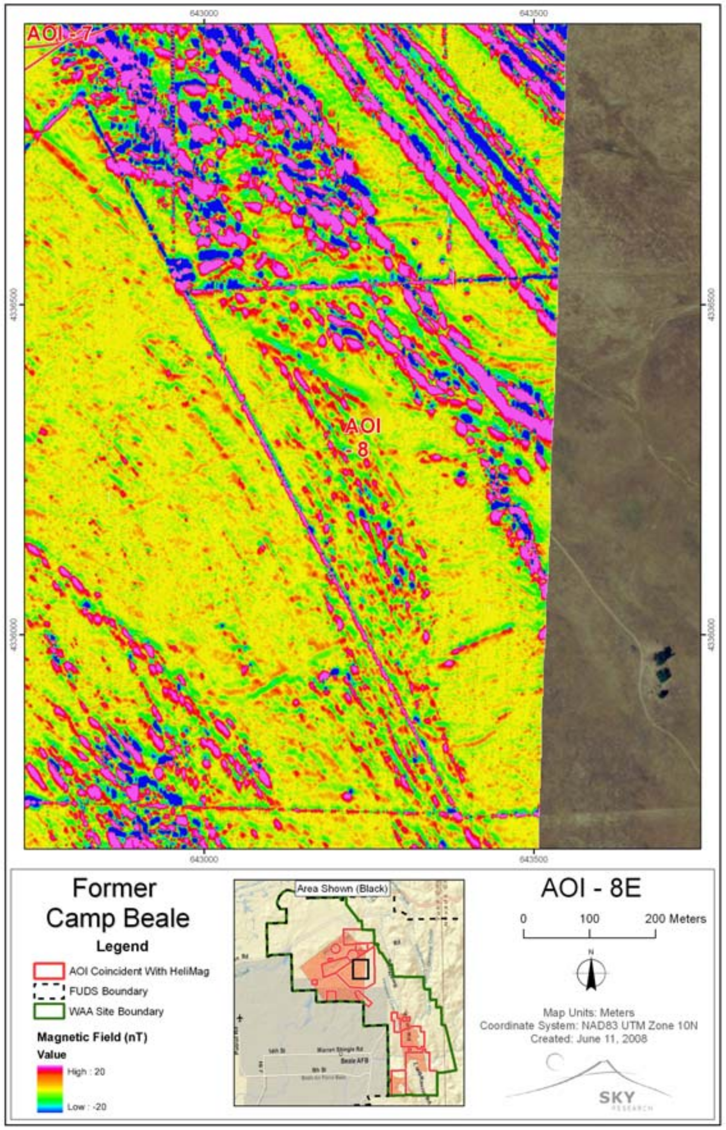
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FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
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Low : -20
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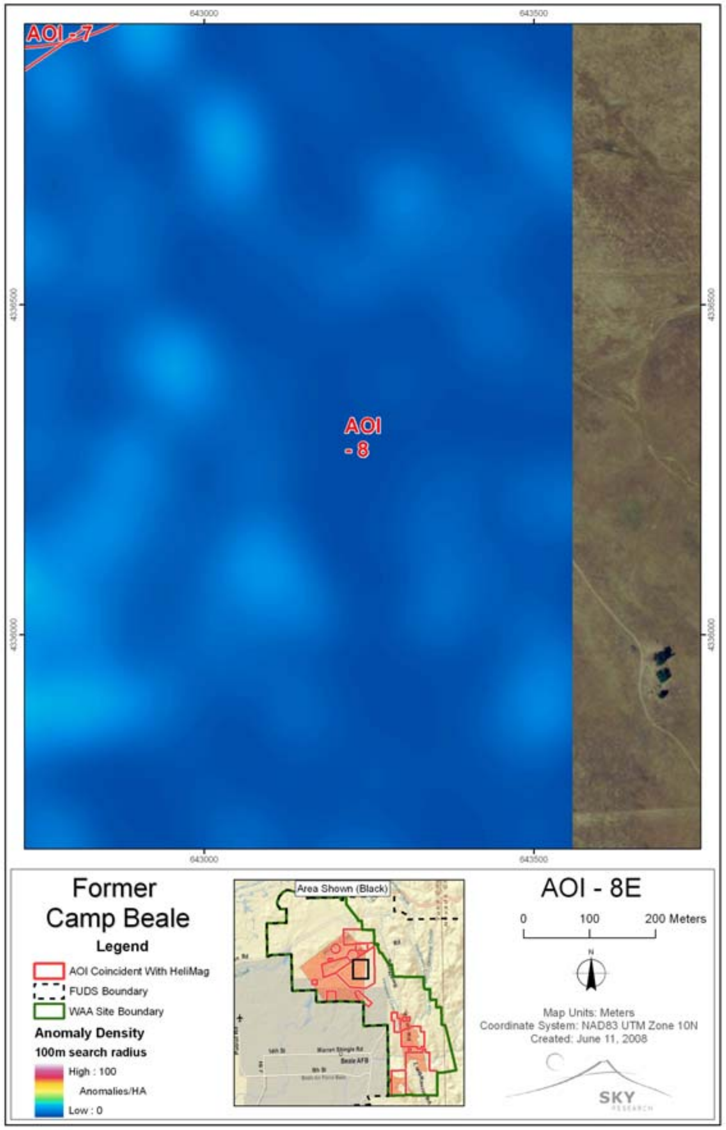
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AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
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WAA Site Boundary
Anomaly Density
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Anomalies/HA
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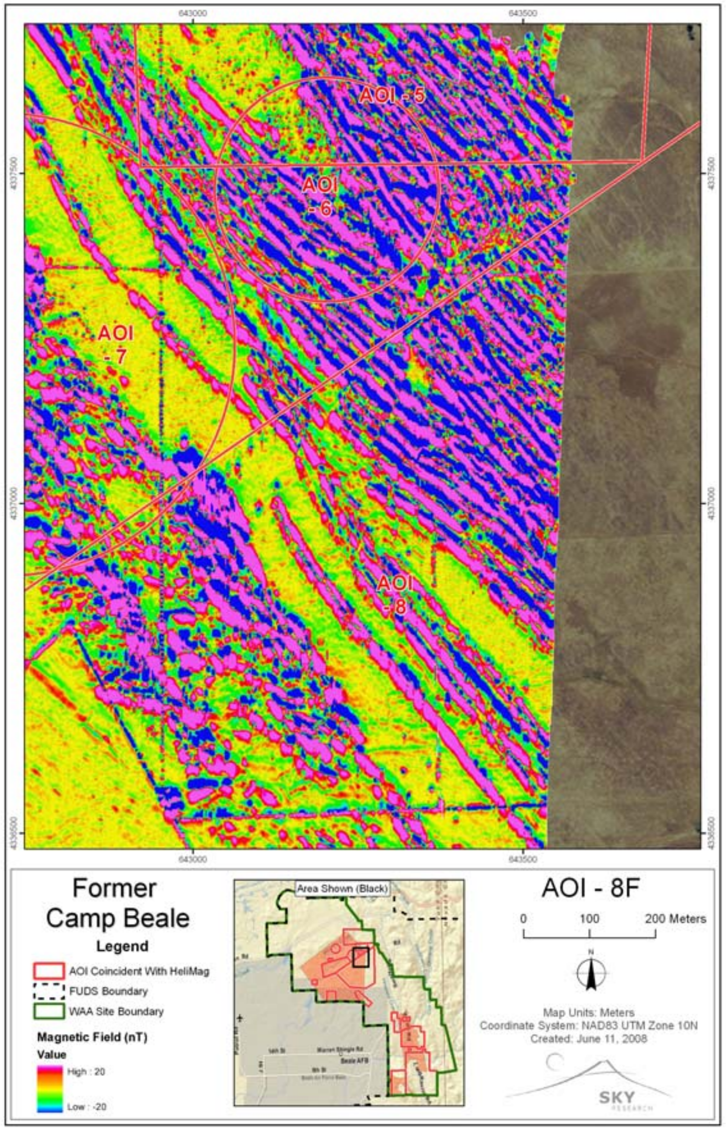
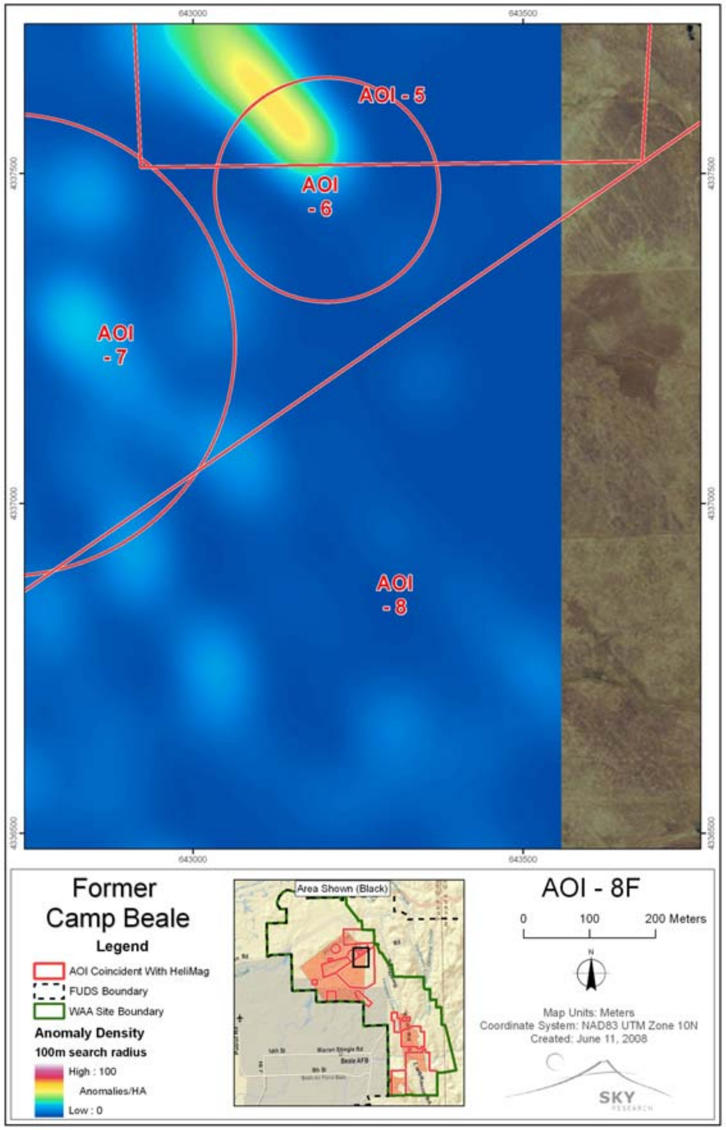
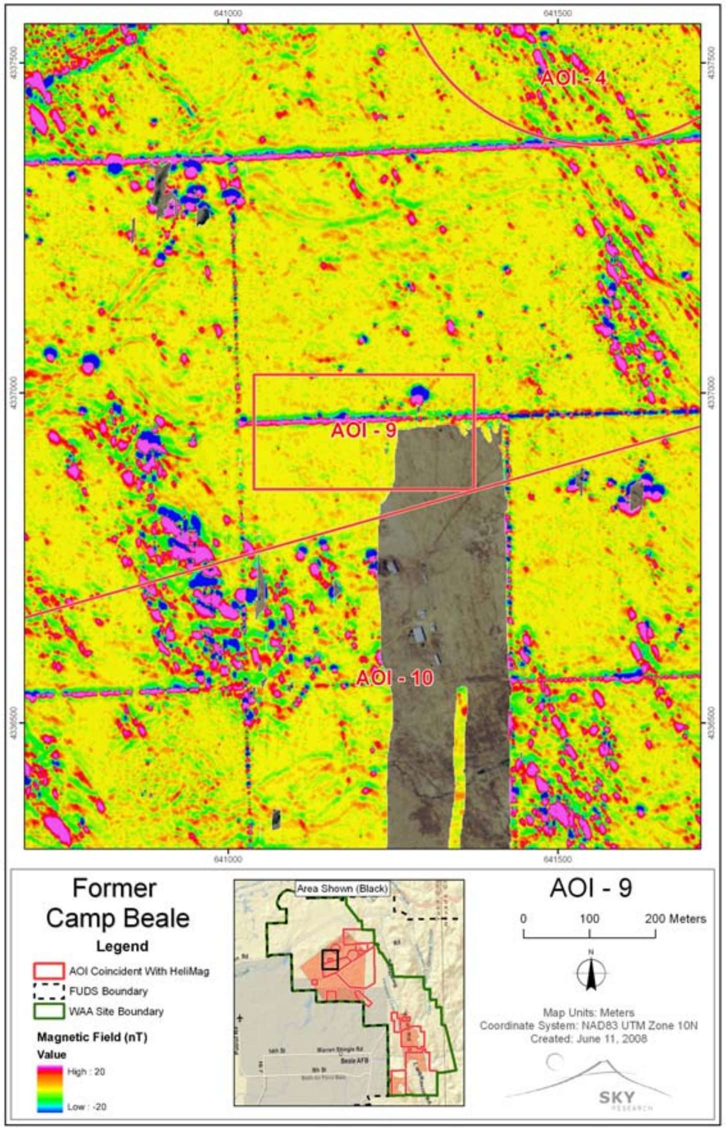
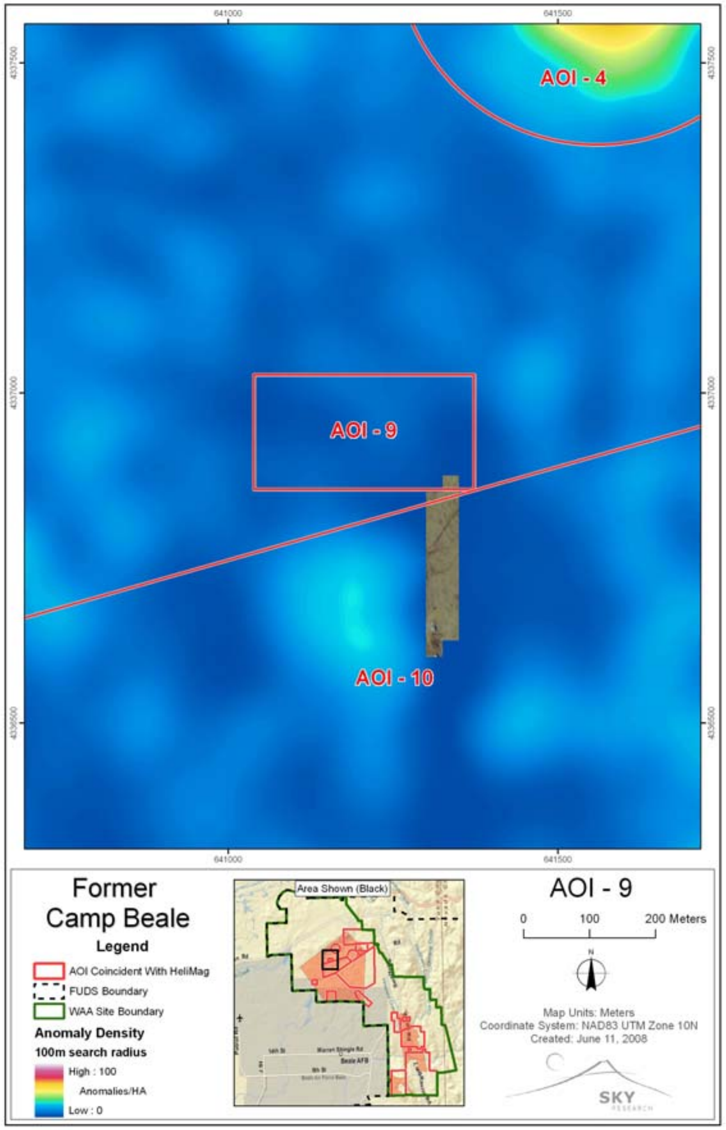
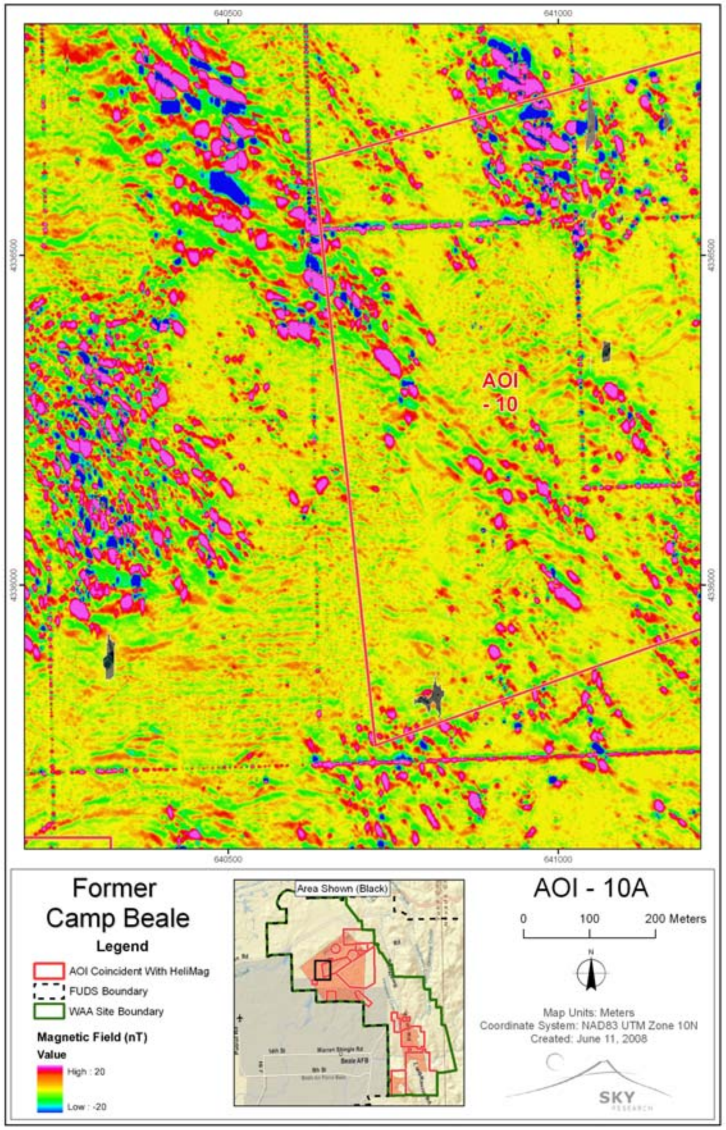
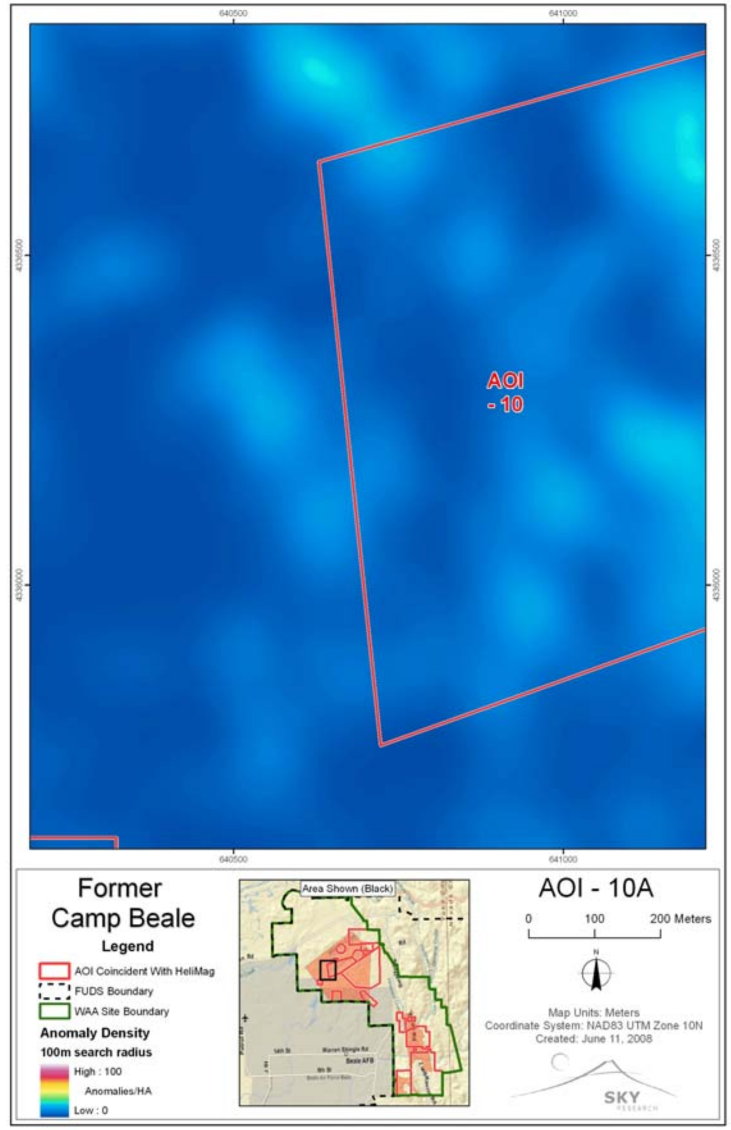

AOI - 5
AOI - 6
AOI - 7
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 8F
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

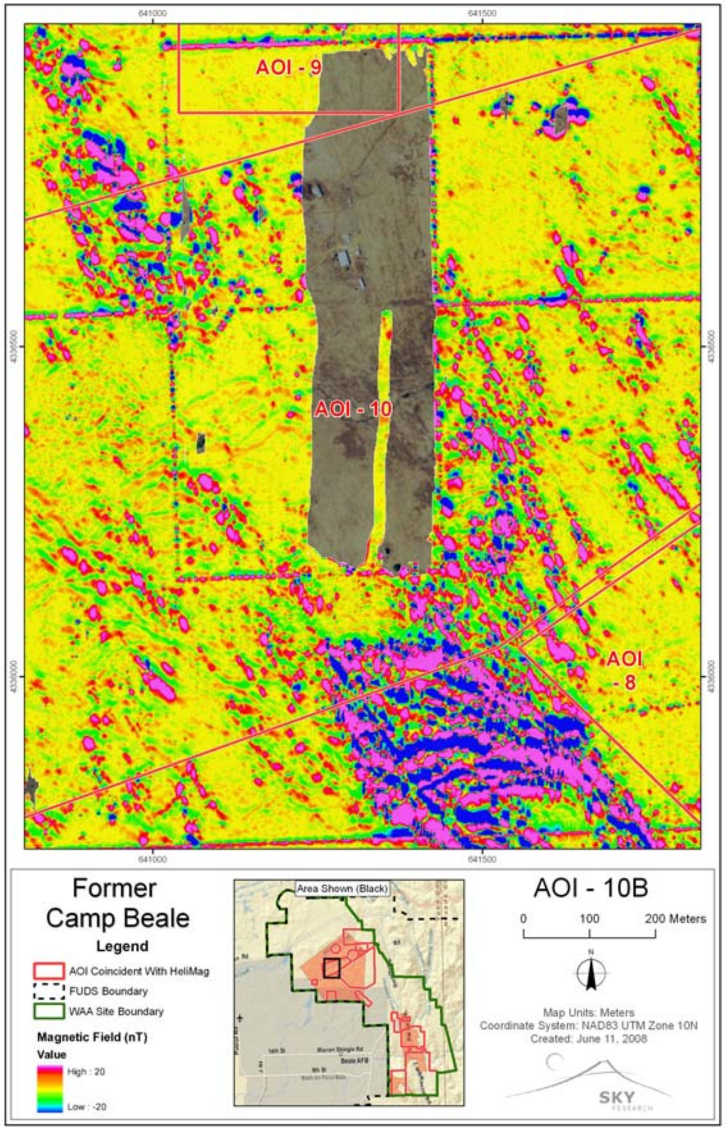

AOI - 5
AOI - 6
AOI - 7
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 8F
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

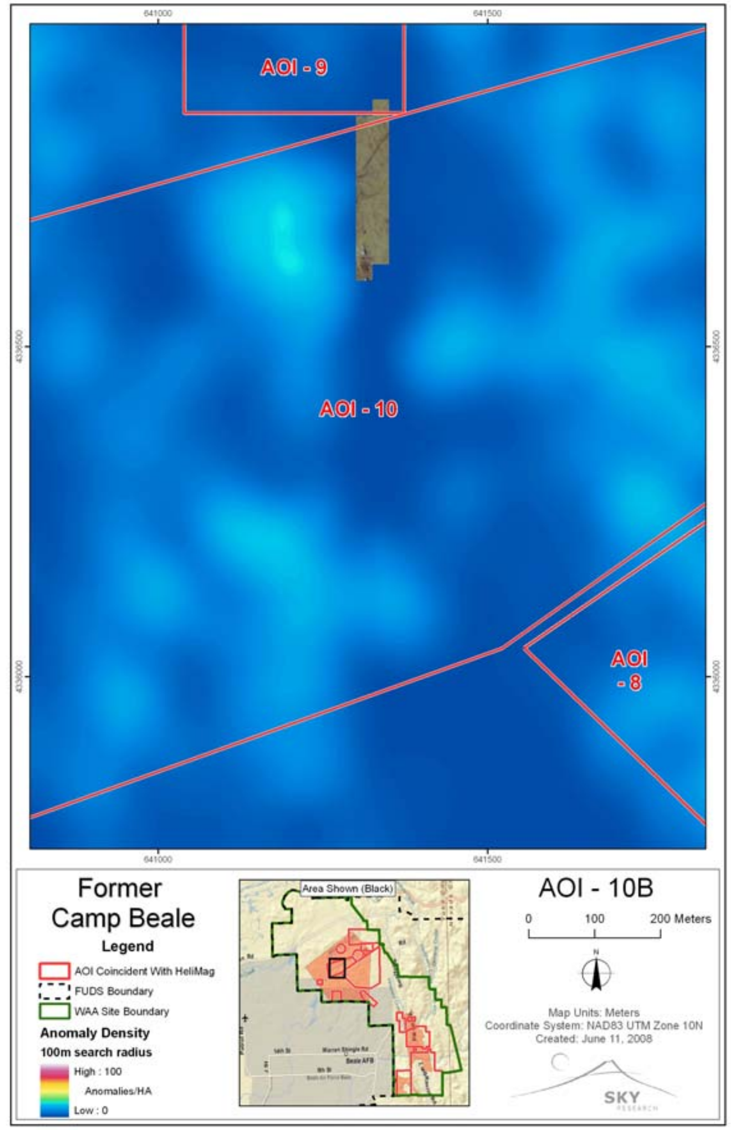

AOI - 4
AOI - 9
AOI - 10
Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 9
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

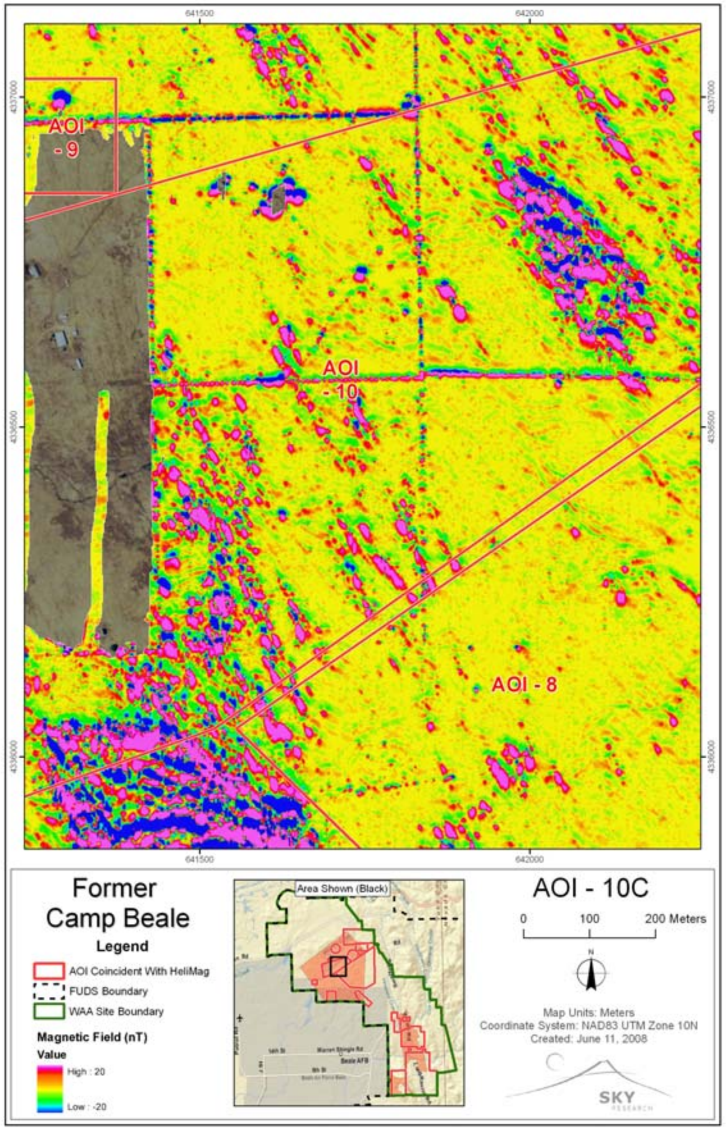

AOI - 4
AOI - 9
AOI - 10
Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 9
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

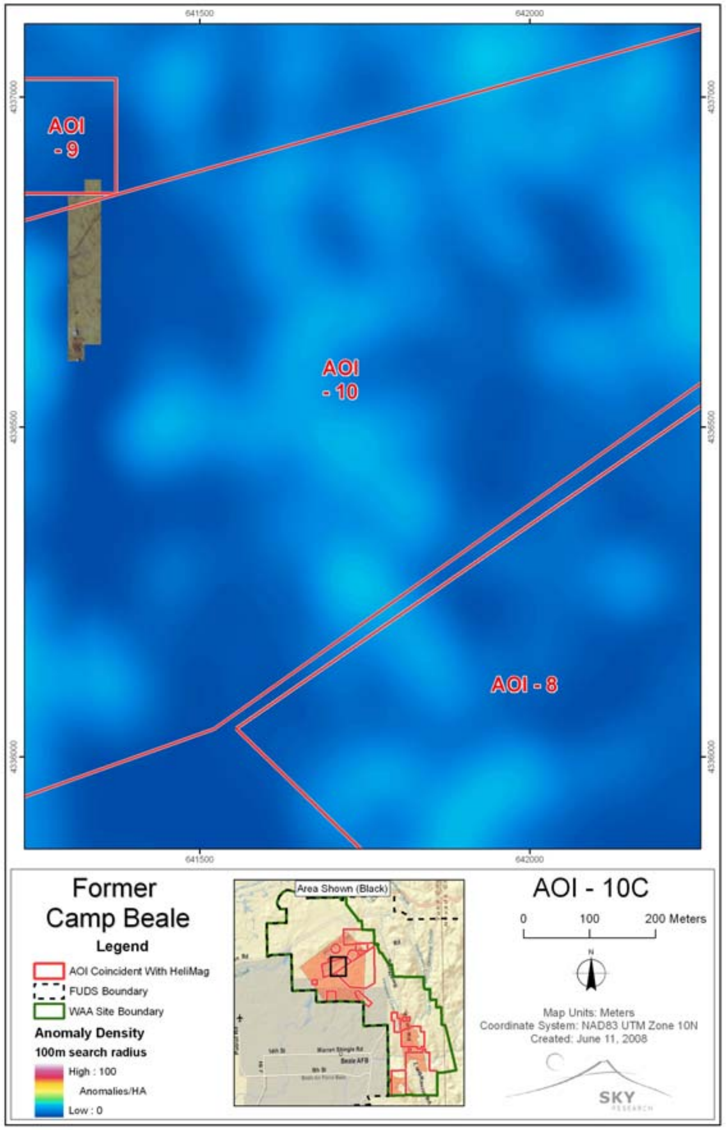

AOI - 10
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 10A
0 100 200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

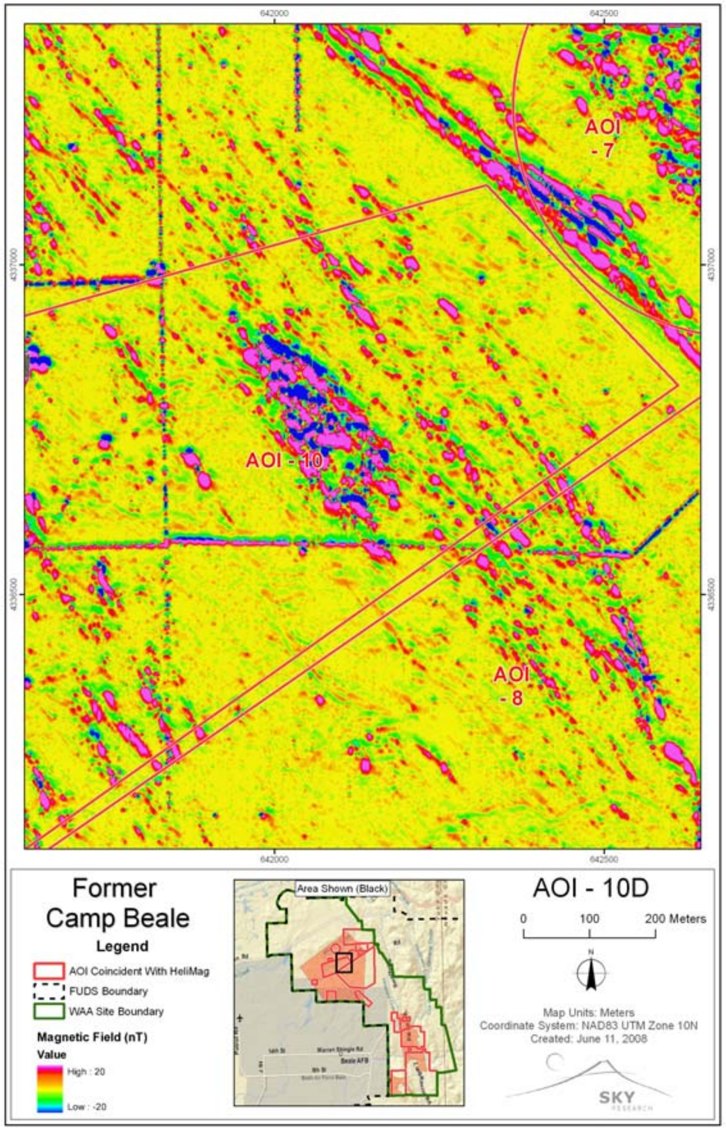

AOI - 10
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 10A
0 100 200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY


AOI - 9
AOI - 10
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 10B
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

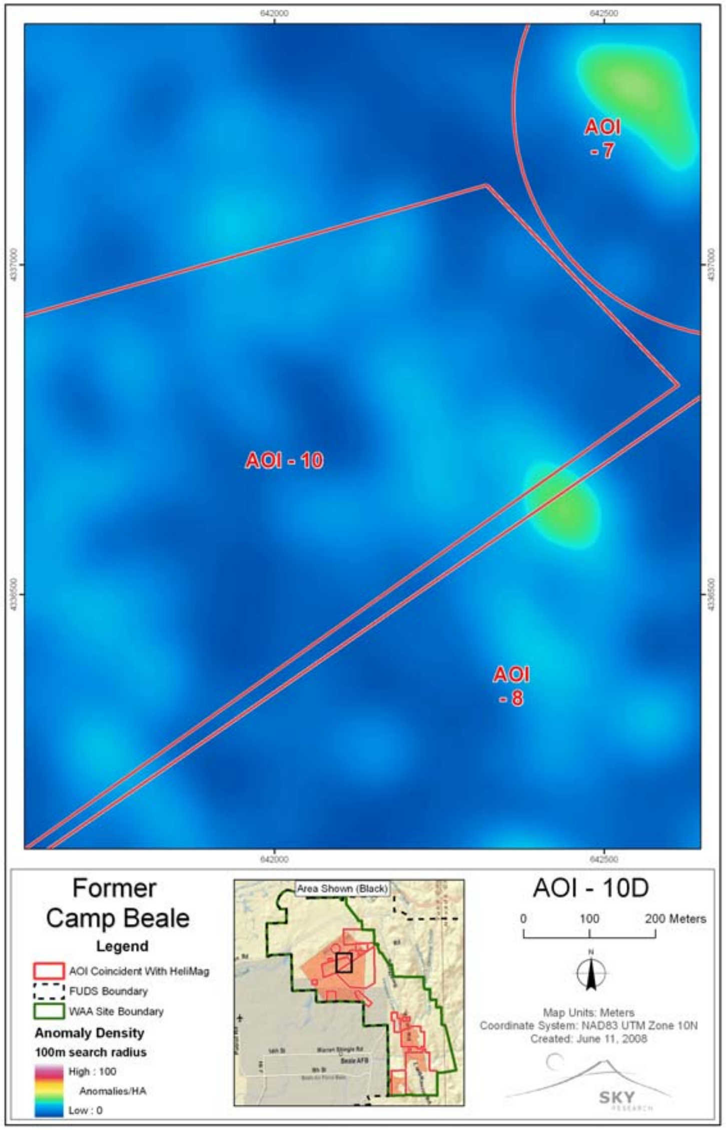

AOI - 9
AOI - 10
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 10B
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY


641500
642000
AOI - 9
AOI - 10
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 10C
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

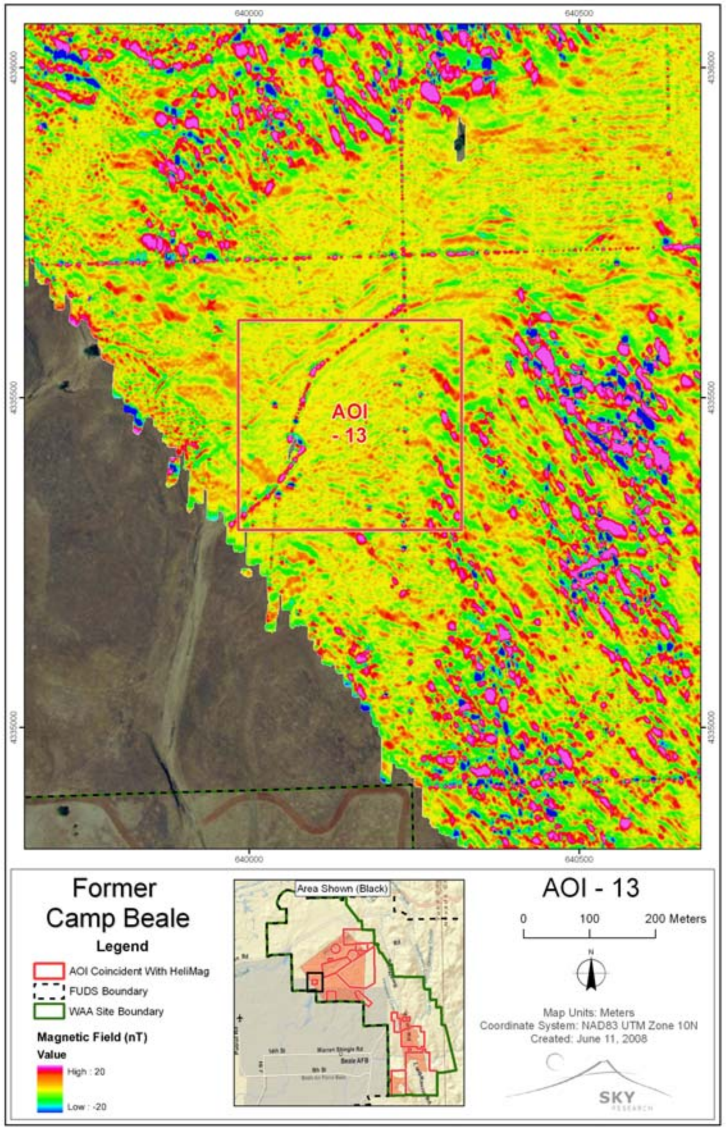

641500
642000
AOI - 9
AOI - 10
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 10C
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

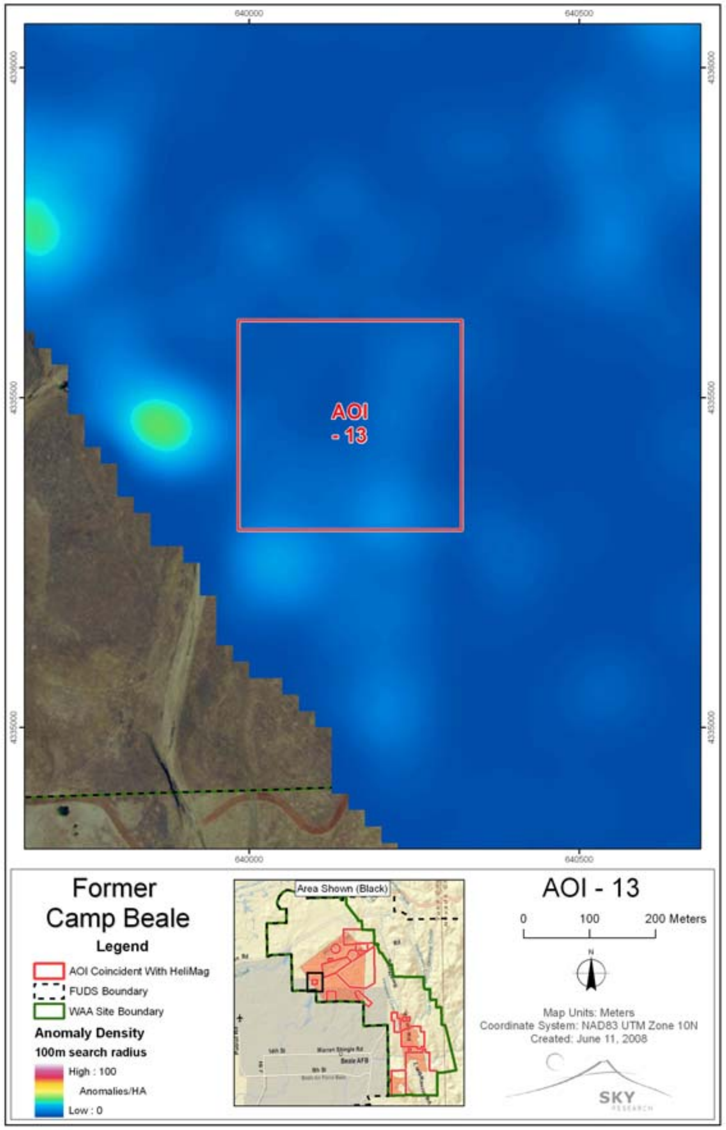


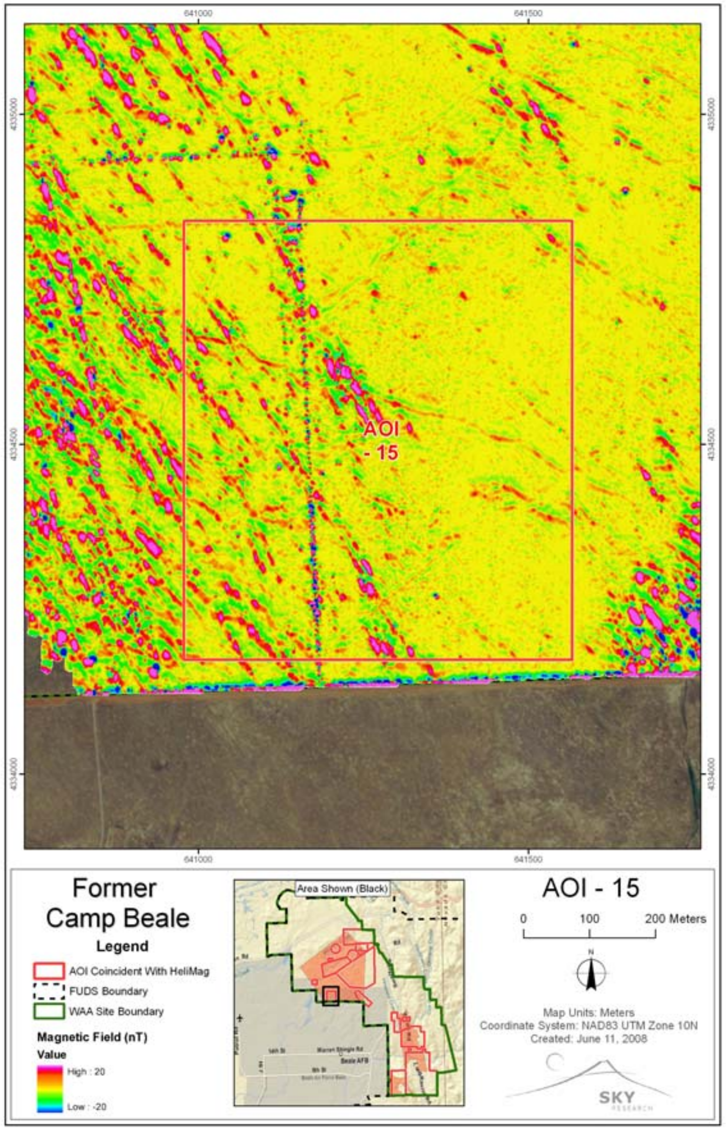
642000
642500
AOI - 7
AOI - 10
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 10D
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

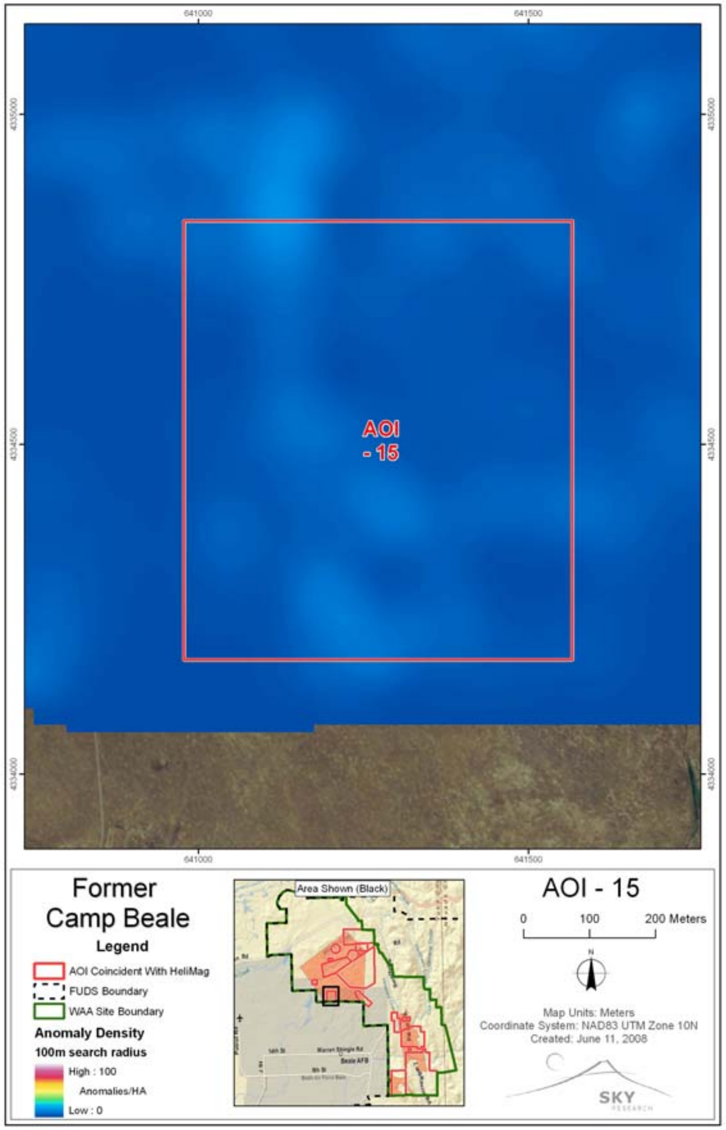


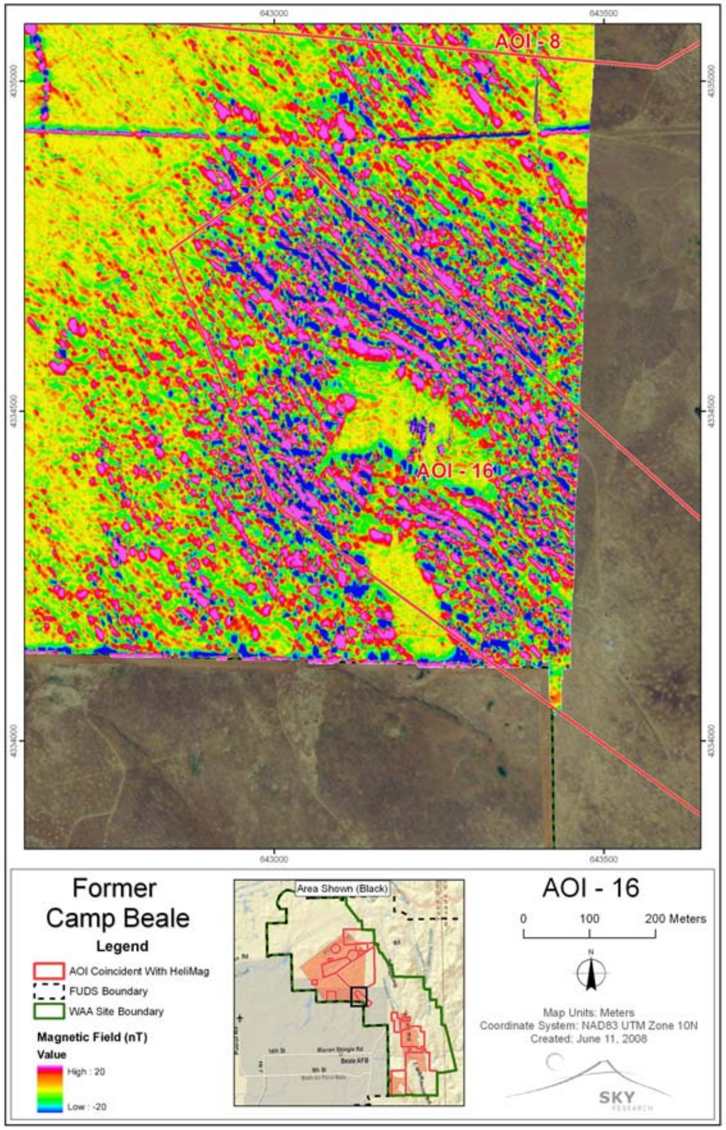
642000
642500
AOI - 7
AOI - 10
AOI - 8
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 10D
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

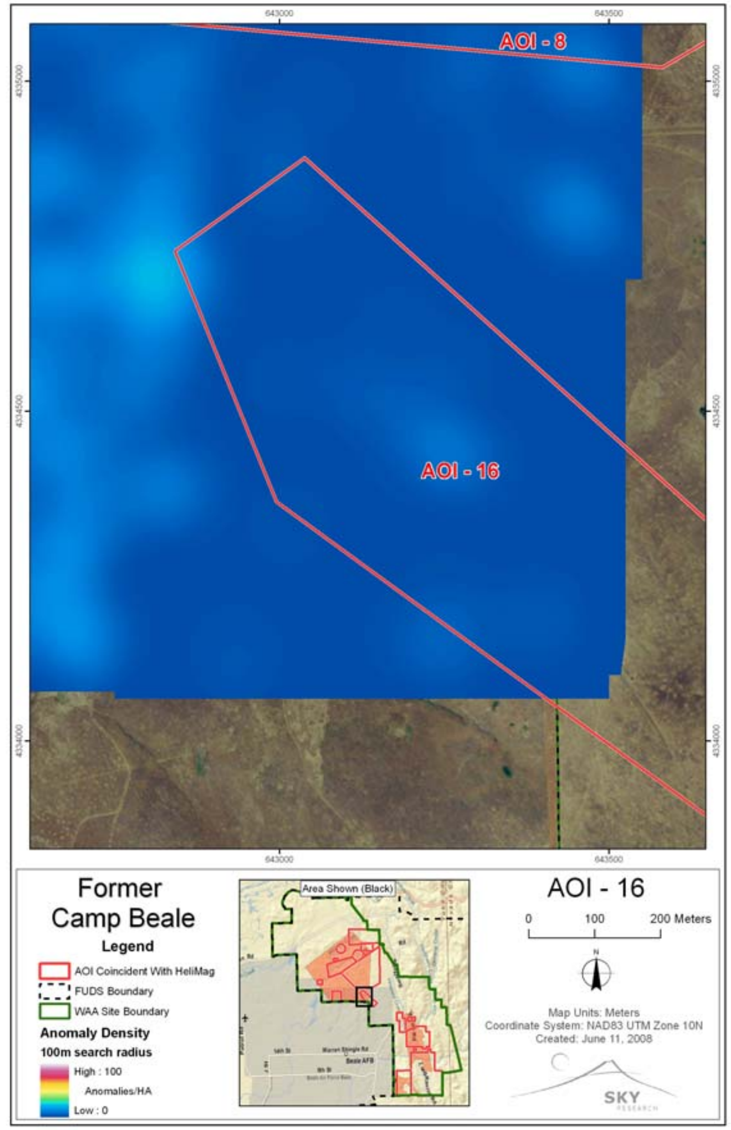

AOI - 13
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 13
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

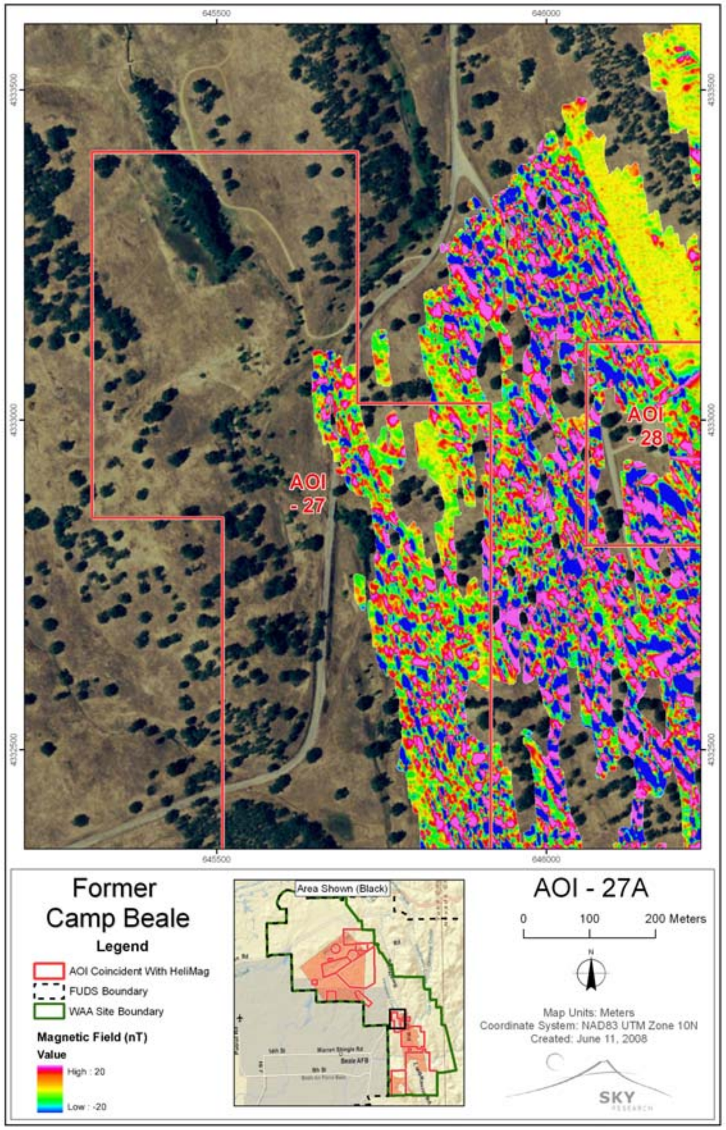

AOI - 13
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 13
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

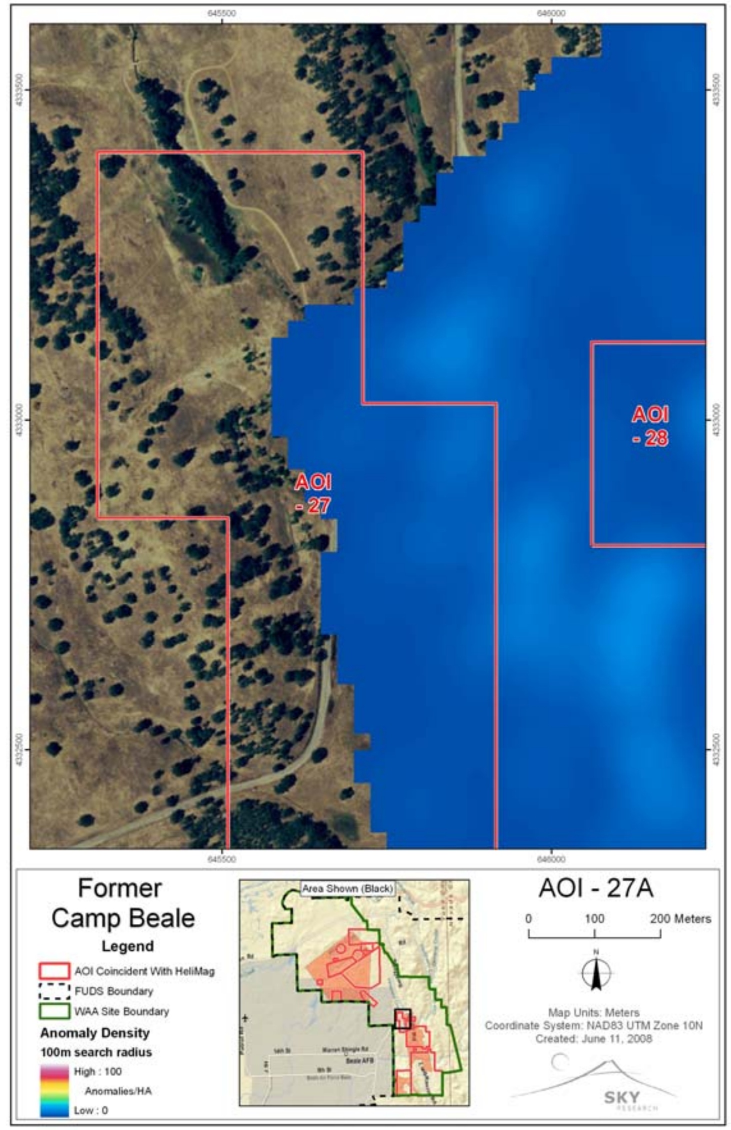

AOI - 15
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 15
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

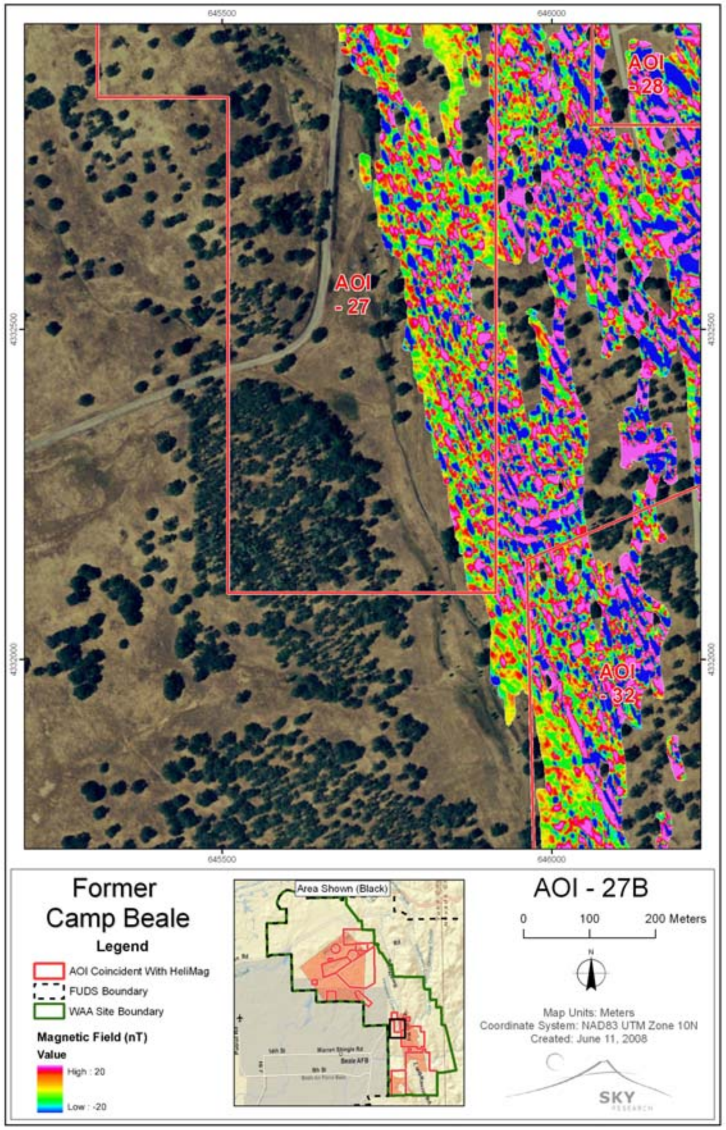

AOI - 15
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 15
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY


AOI - 8
AOI - 16
Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 16
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

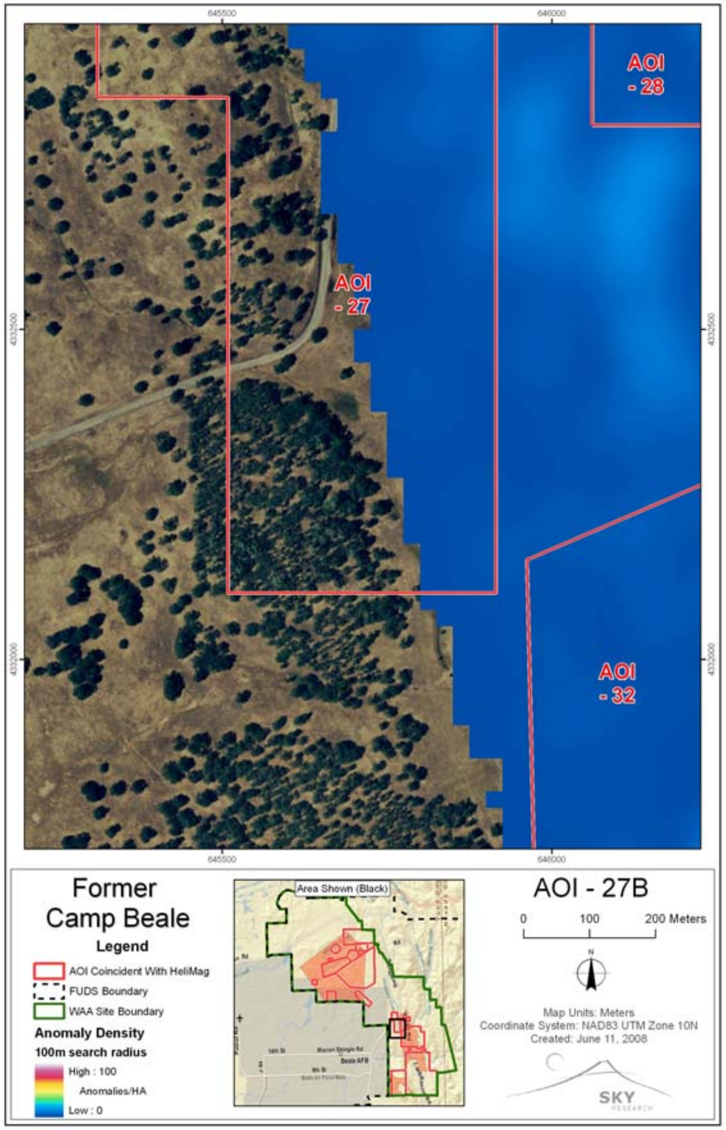

AOI - 8
AOI - 16
Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 16
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY


AOI - 27
AOI - 28
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 27A
0
100
200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

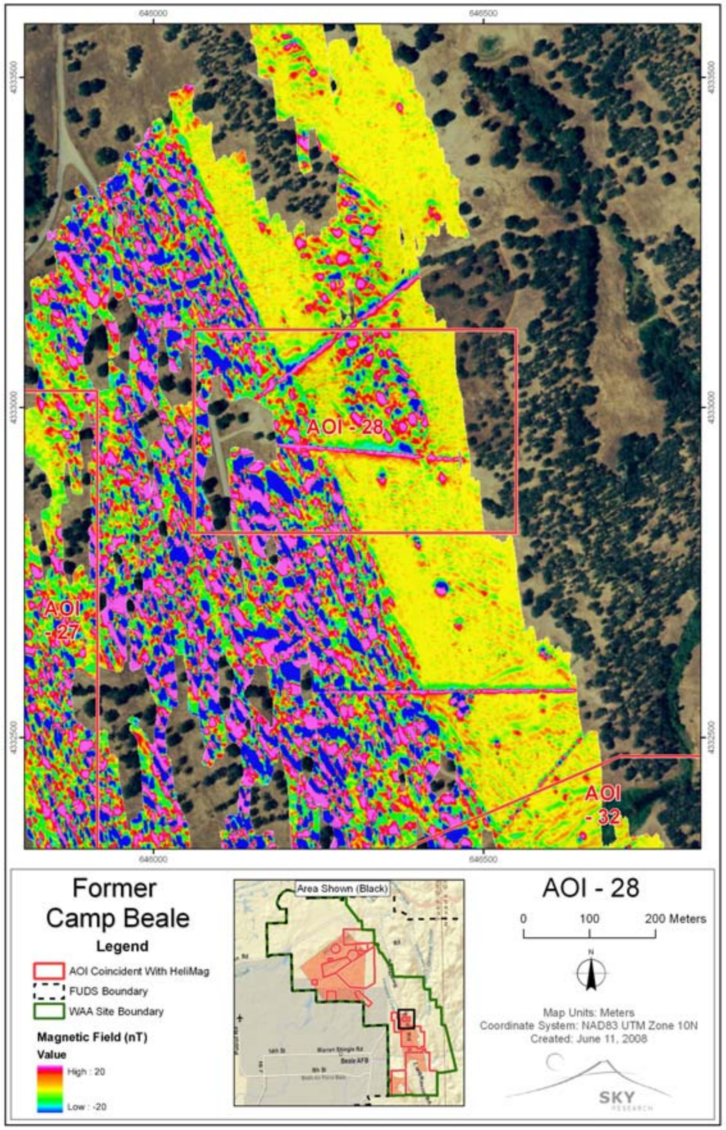

AOI - 27
AOI - 28
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 27A
0
100
200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

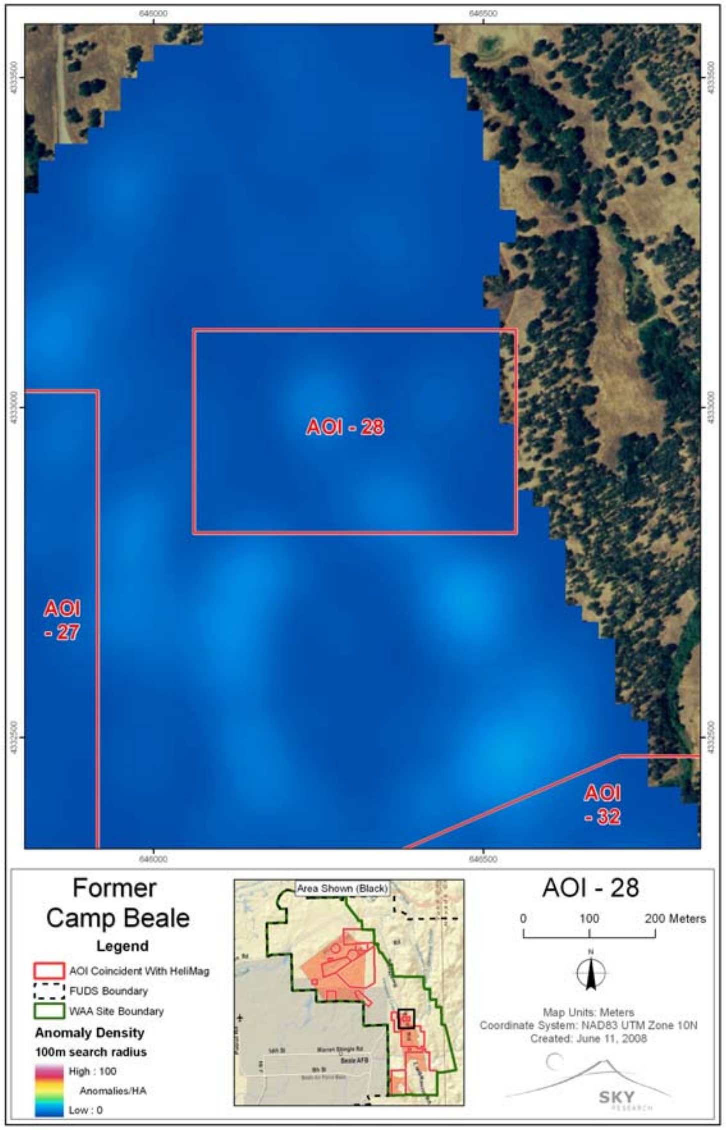


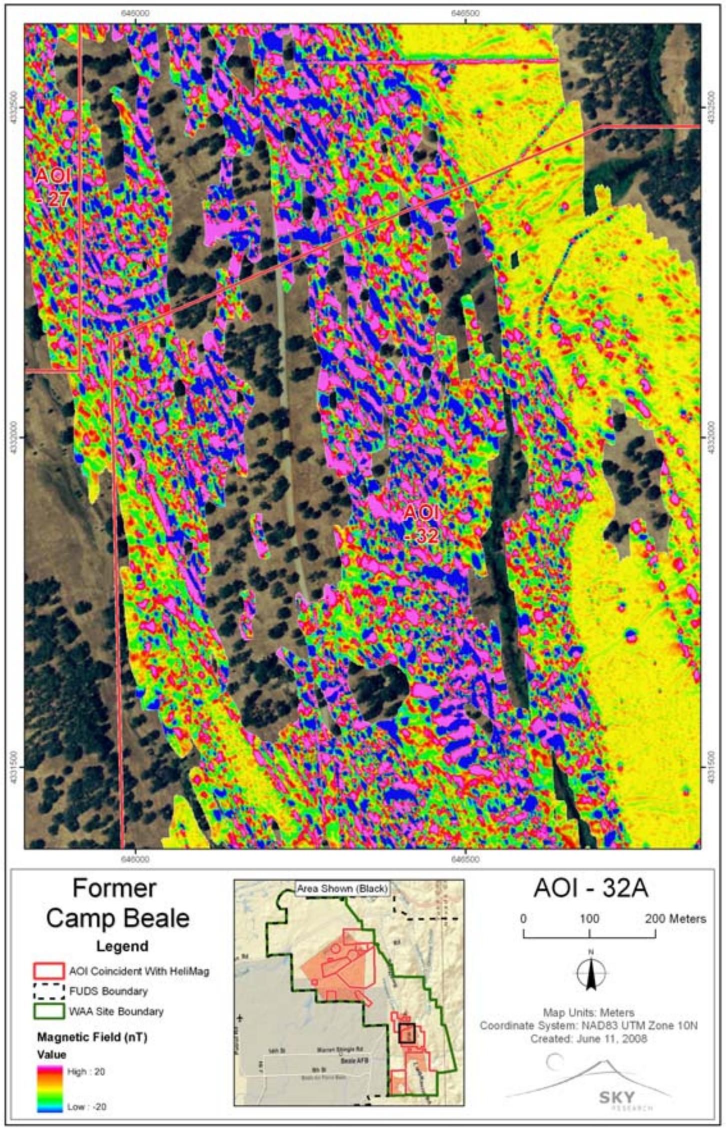
AOI - 28
AOI - 27
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 27B
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

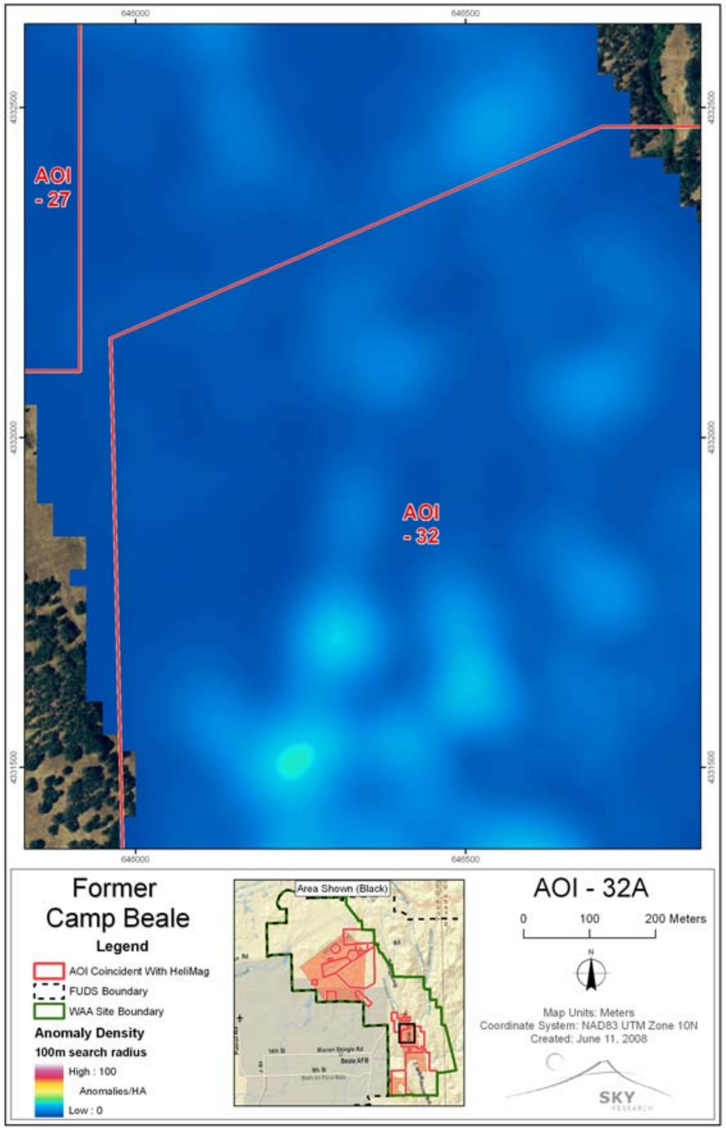


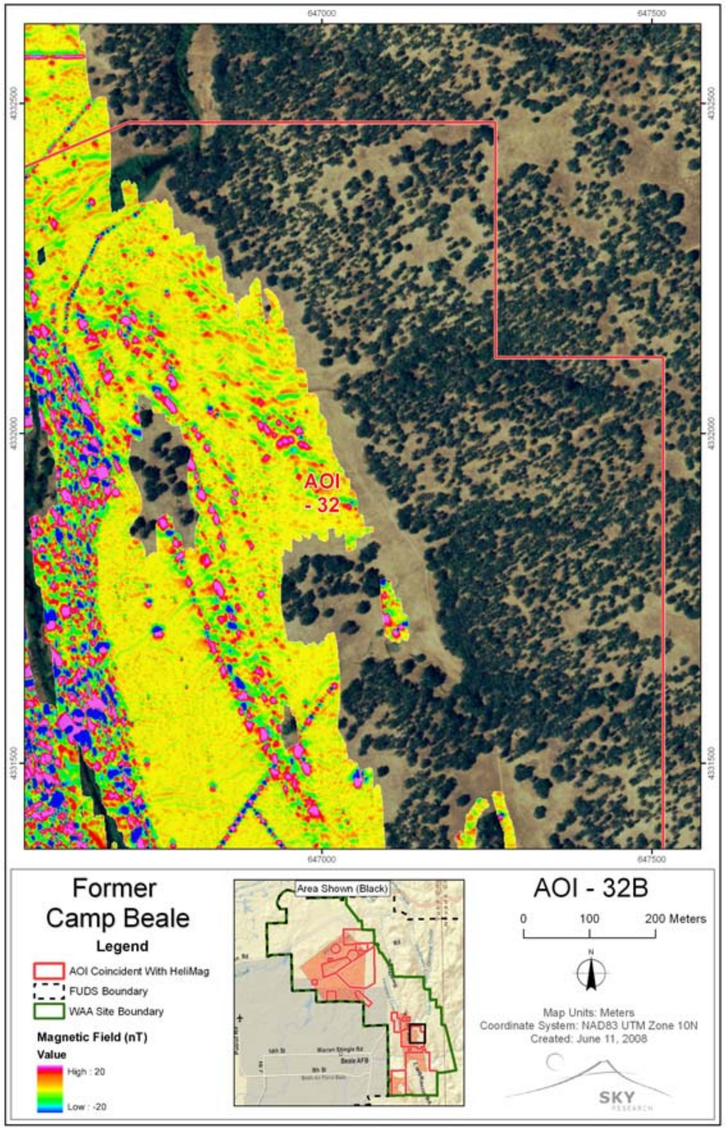
AOI - 28
AOI - 27
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 27B
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

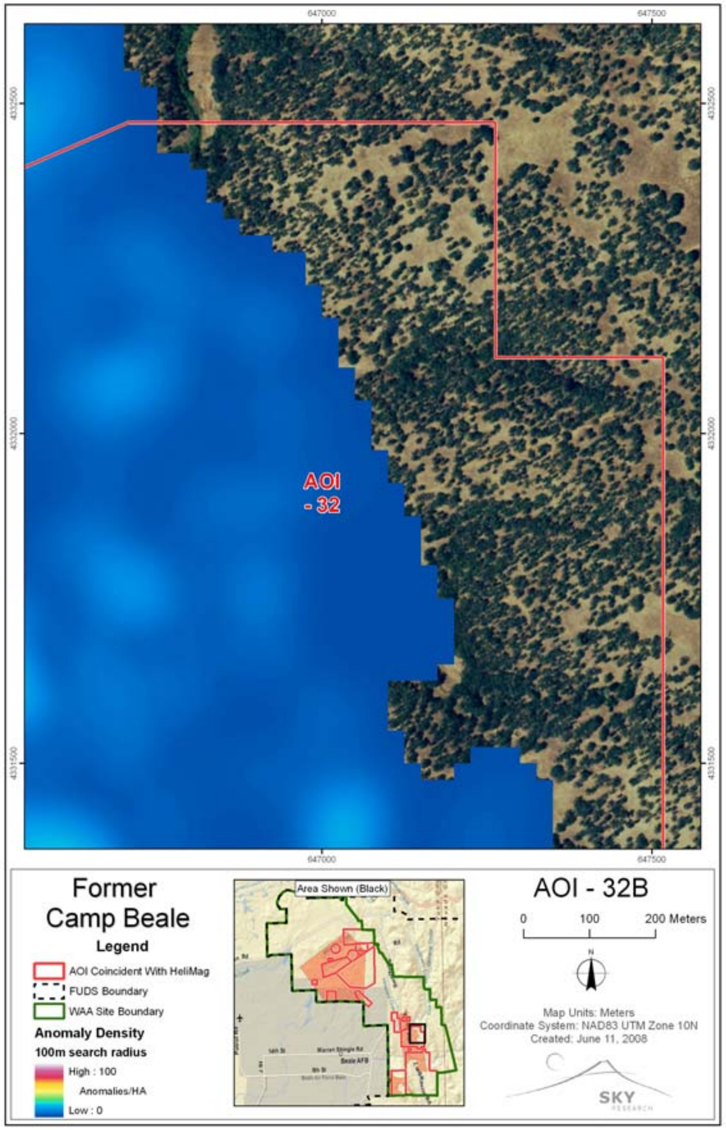

AOI - 28
AOI - 27
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 28
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

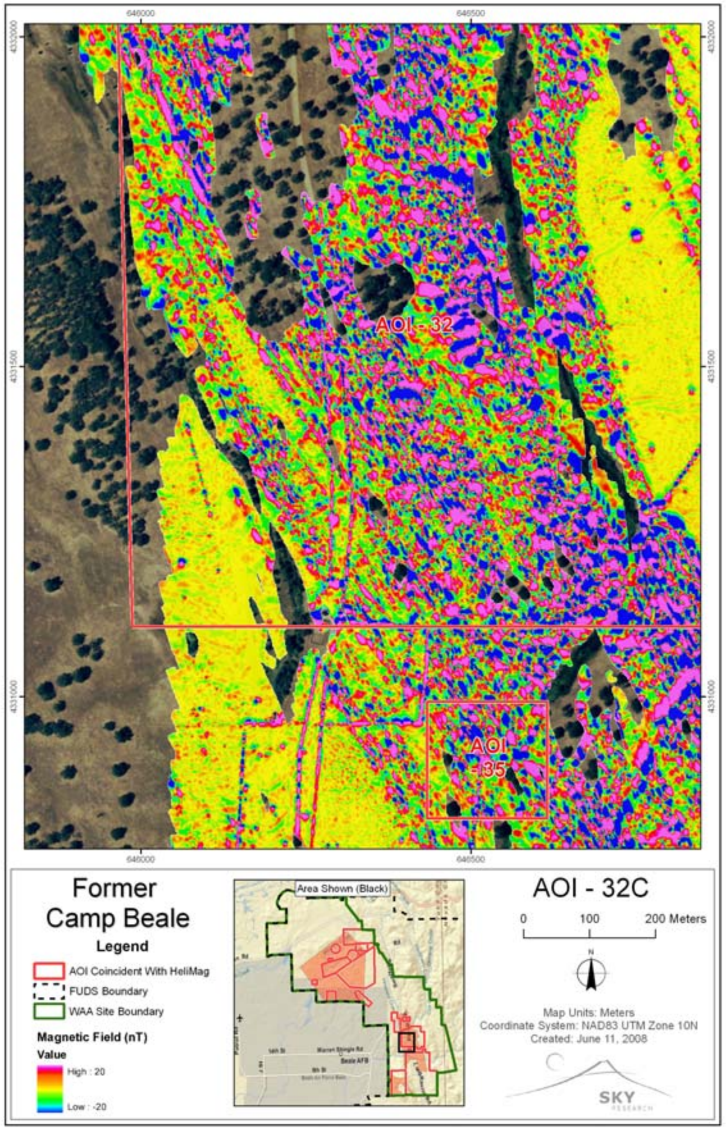

AOI - 28
AOI - 27
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 28
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

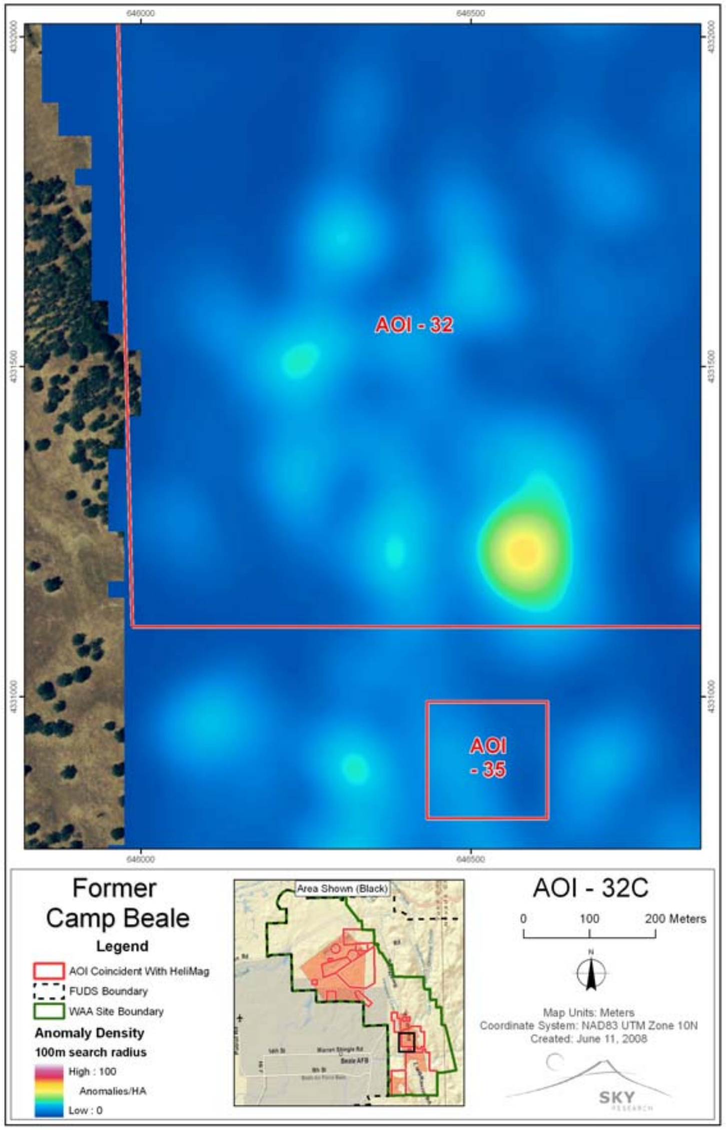

AOI - 27
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 32A
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

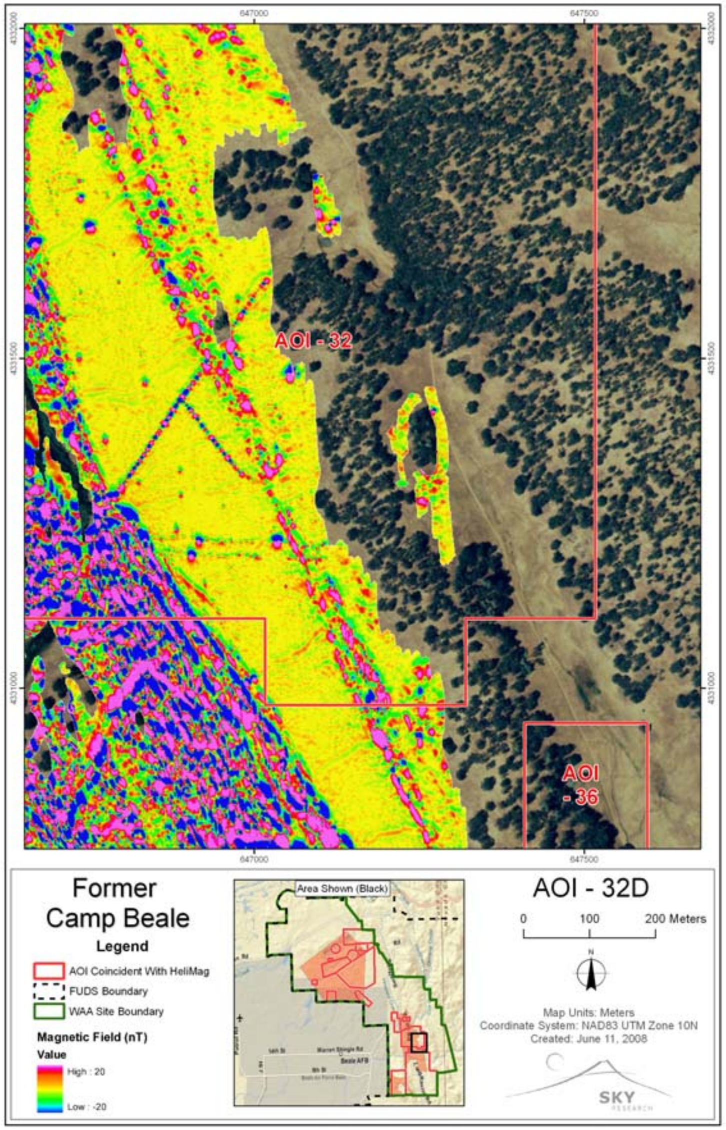

AOI - 27
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 32A
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

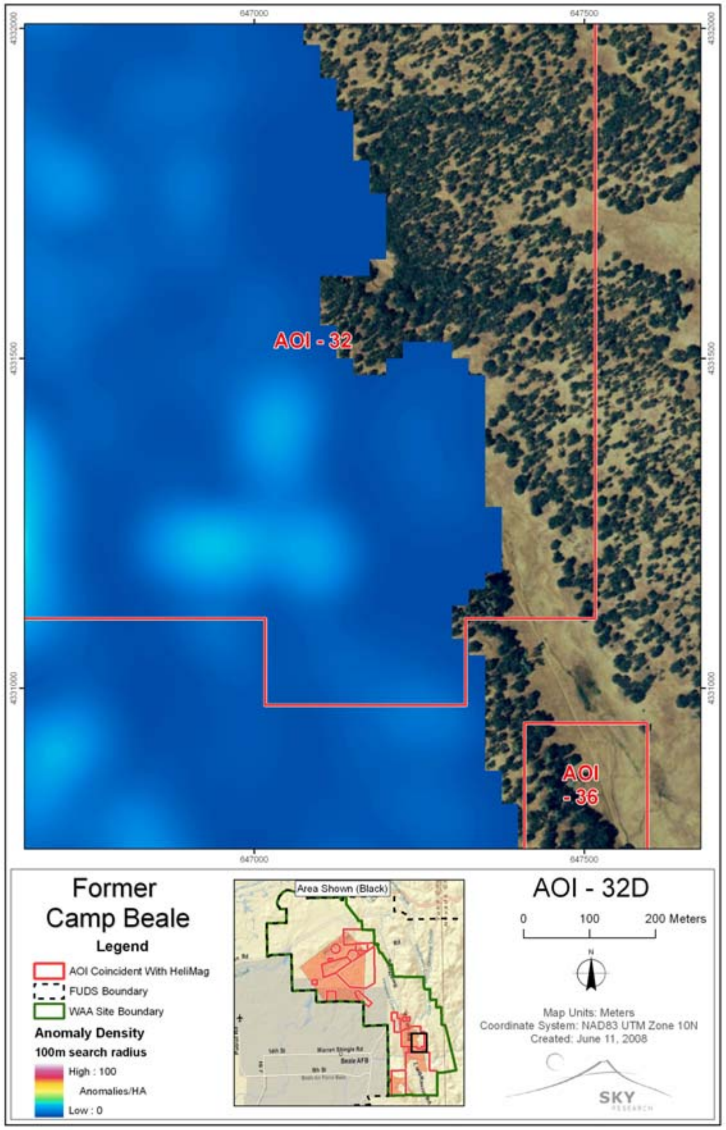

647000
647500
4332500
4332000
4331500
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 32B
0
100
200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

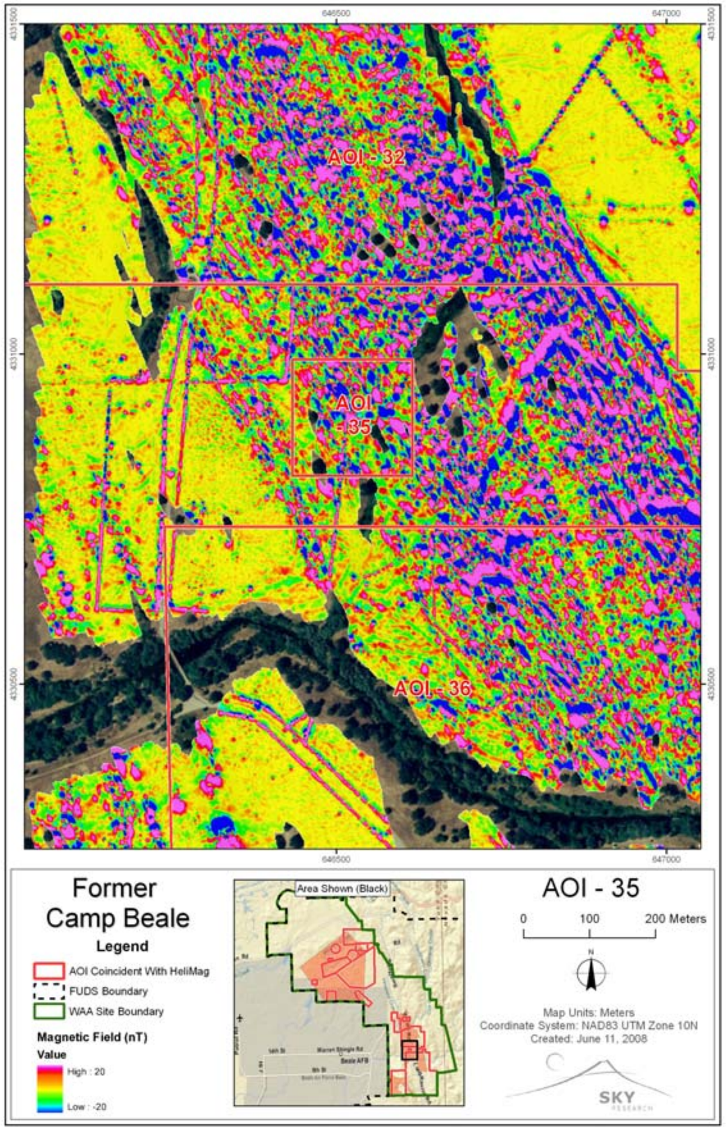

647000
647500
4332500
4332000
4331500
AOI - 32
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 32B
0
100
200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

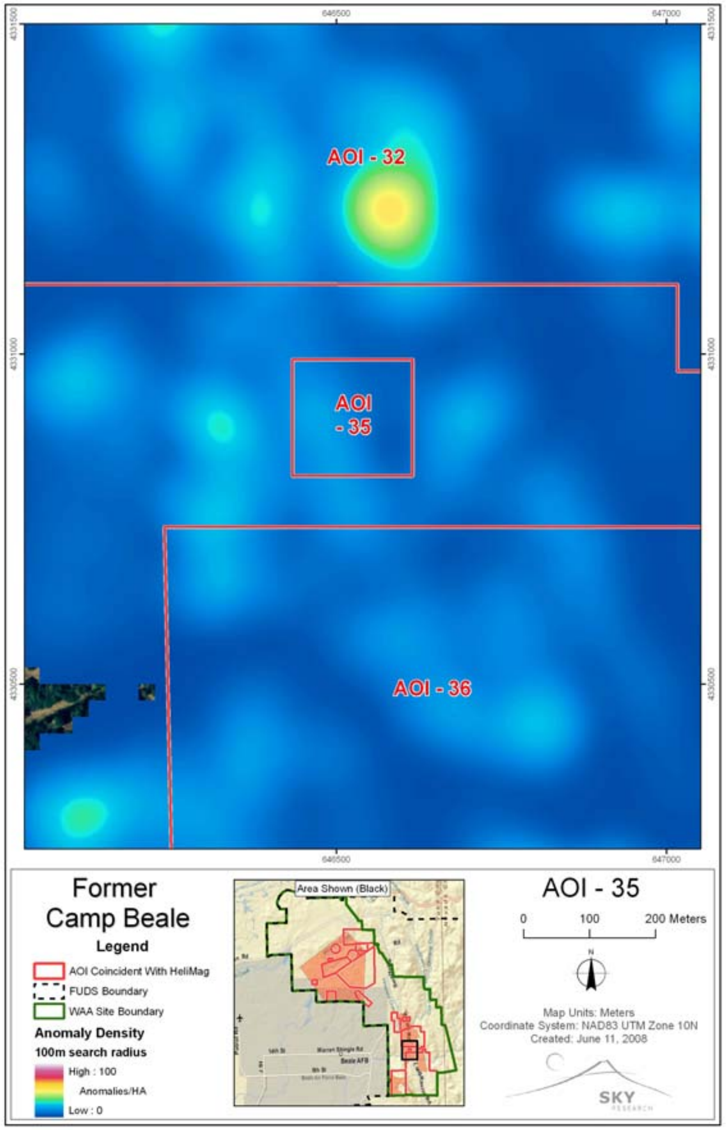

AOI - 32
AOI - 35
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 32C
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

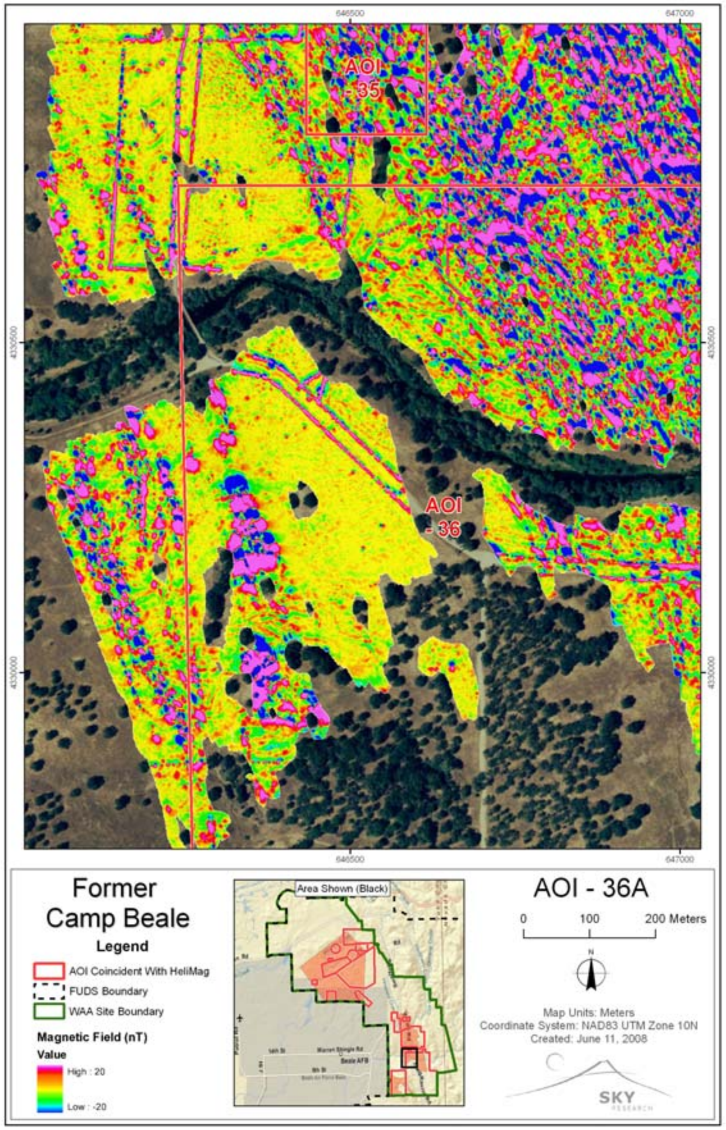

AOI - 32
AOI - 35
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 32C
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

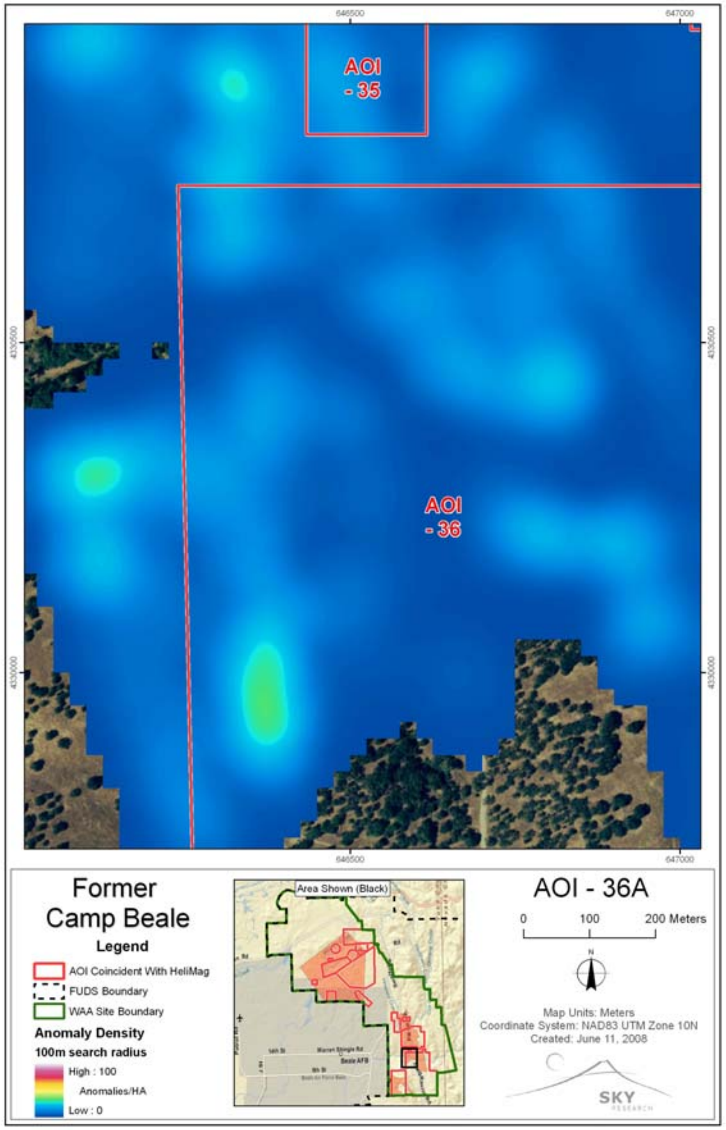

AOI - 32
AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 32D
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

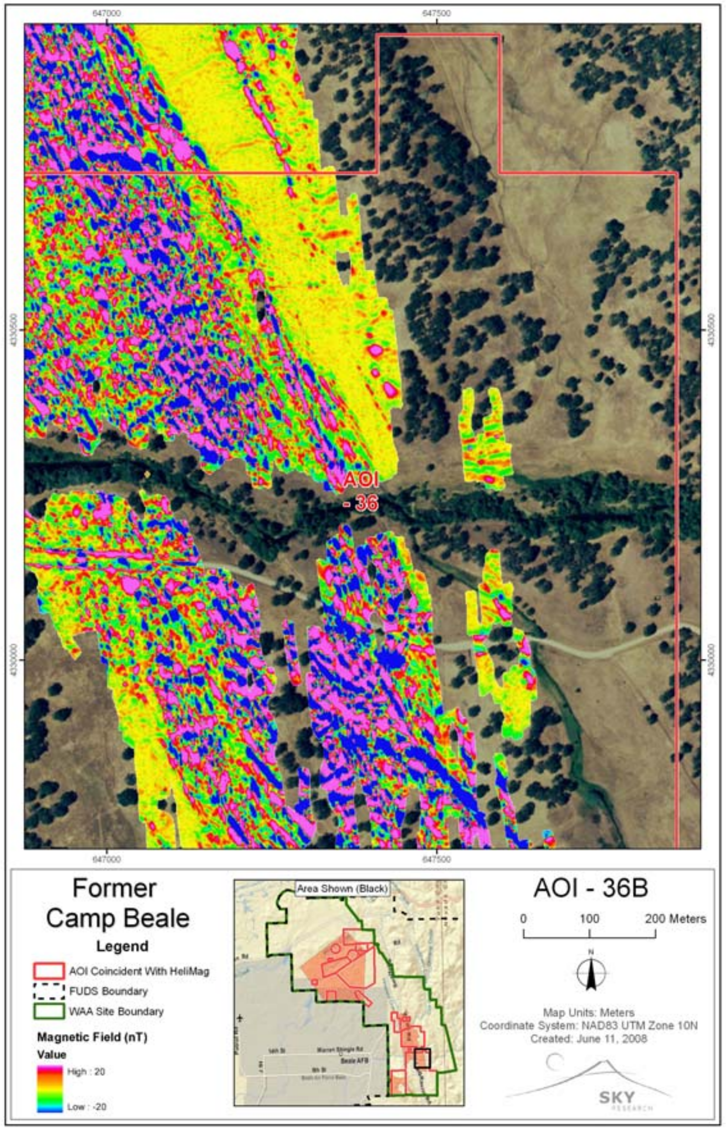

AOI - 32
AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 32D
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

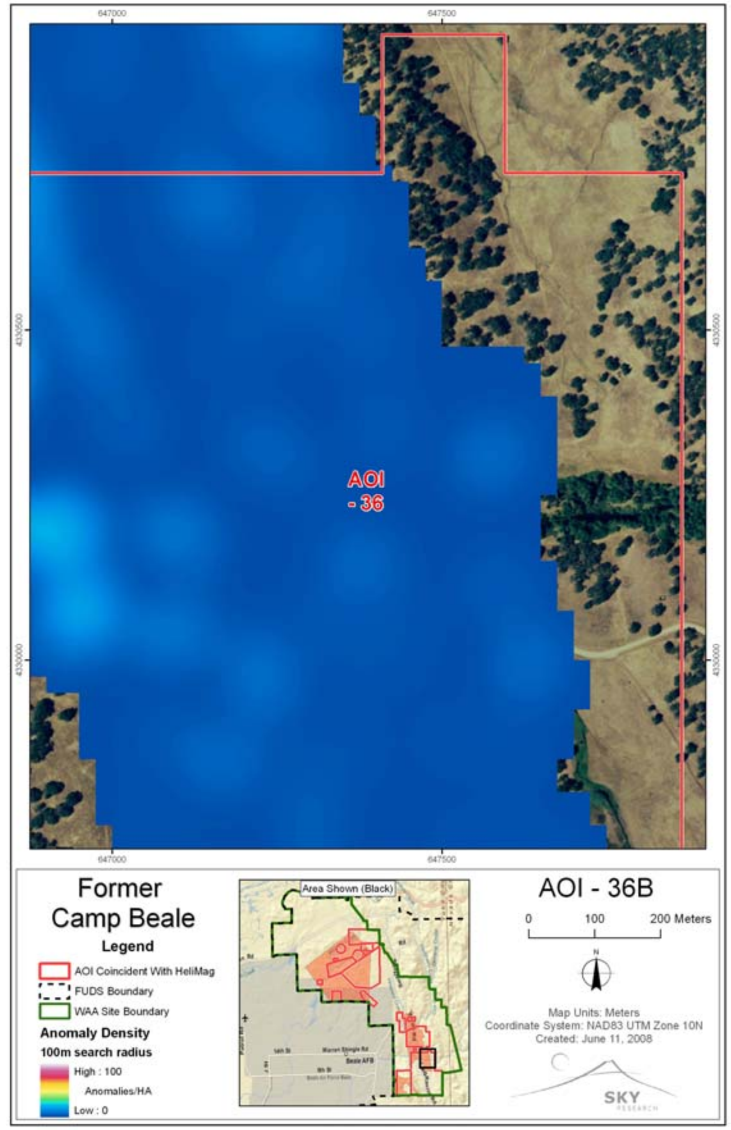

AOI - 32
AOI - 35
AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 35
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008

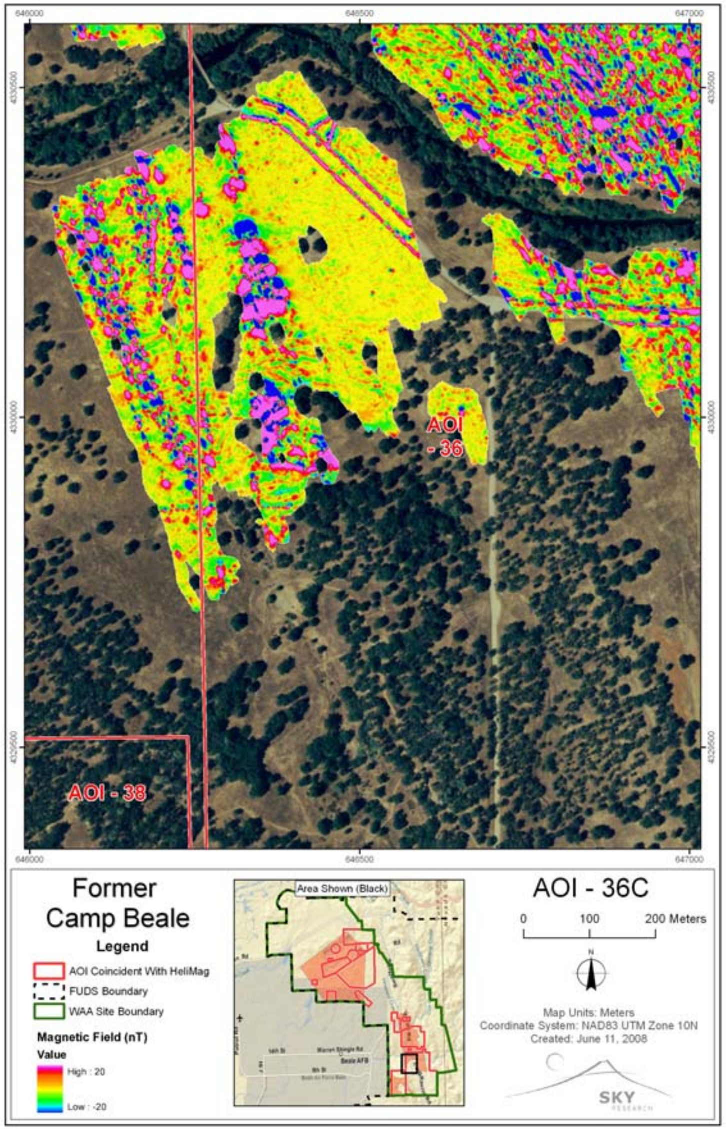

AOI - 32
AOI - 35
AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 35
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008

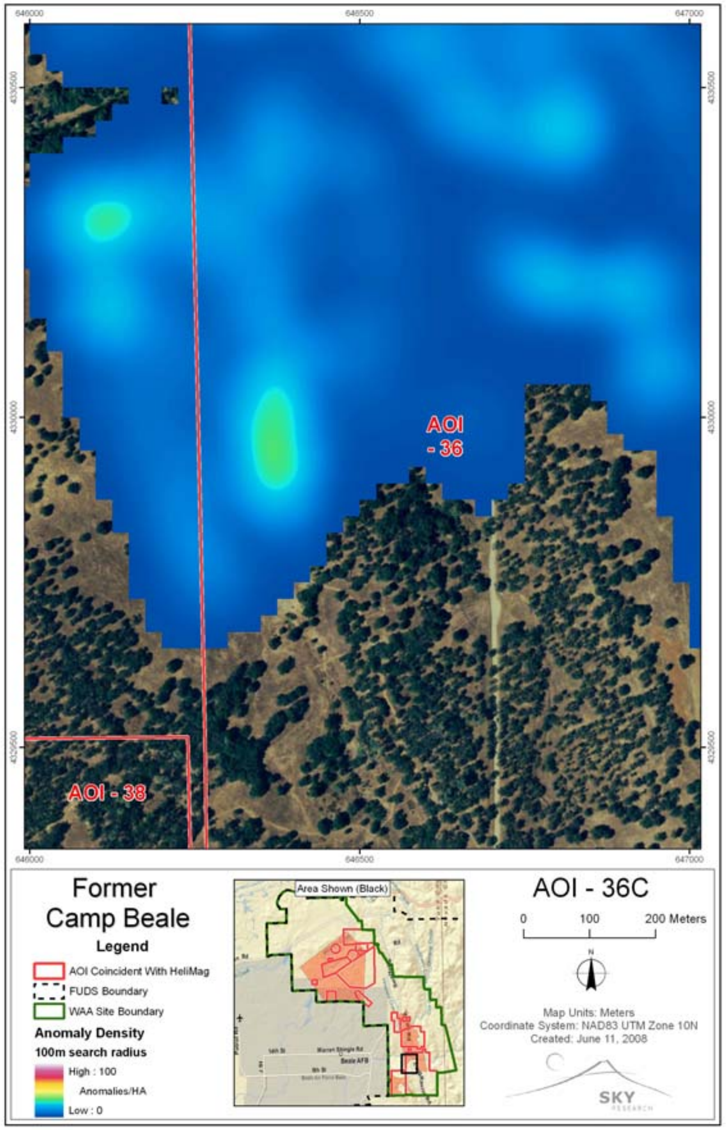

AOI - 35
AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 36A
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

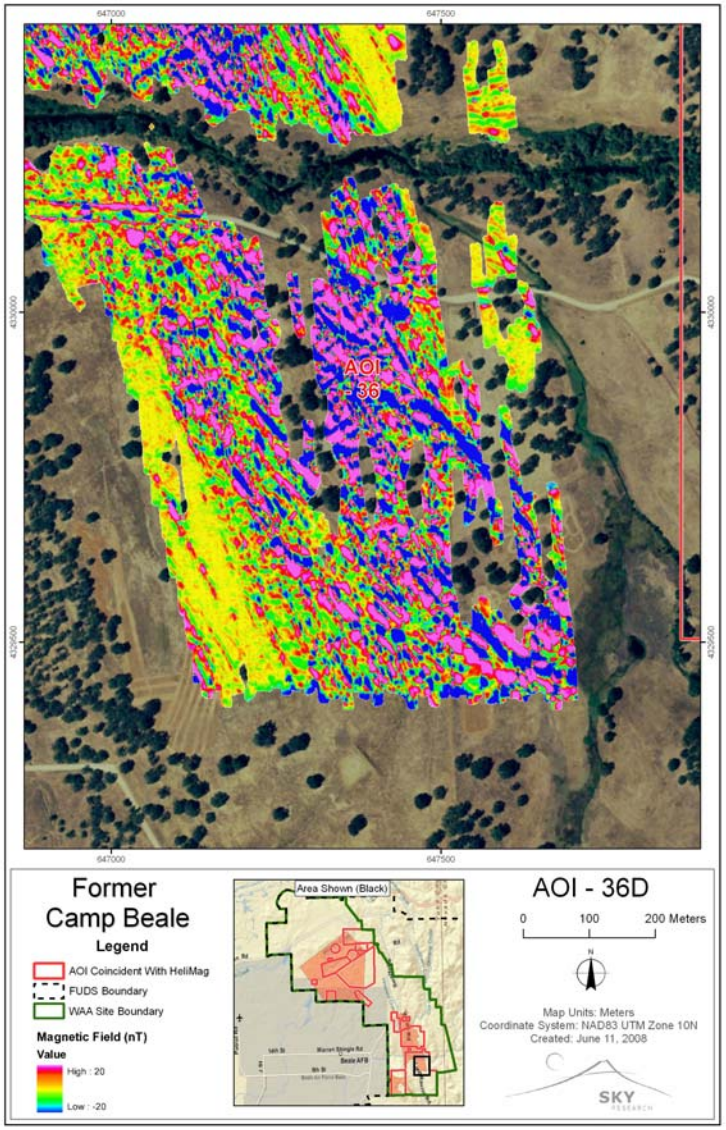

AOI - 35
AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 36A
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

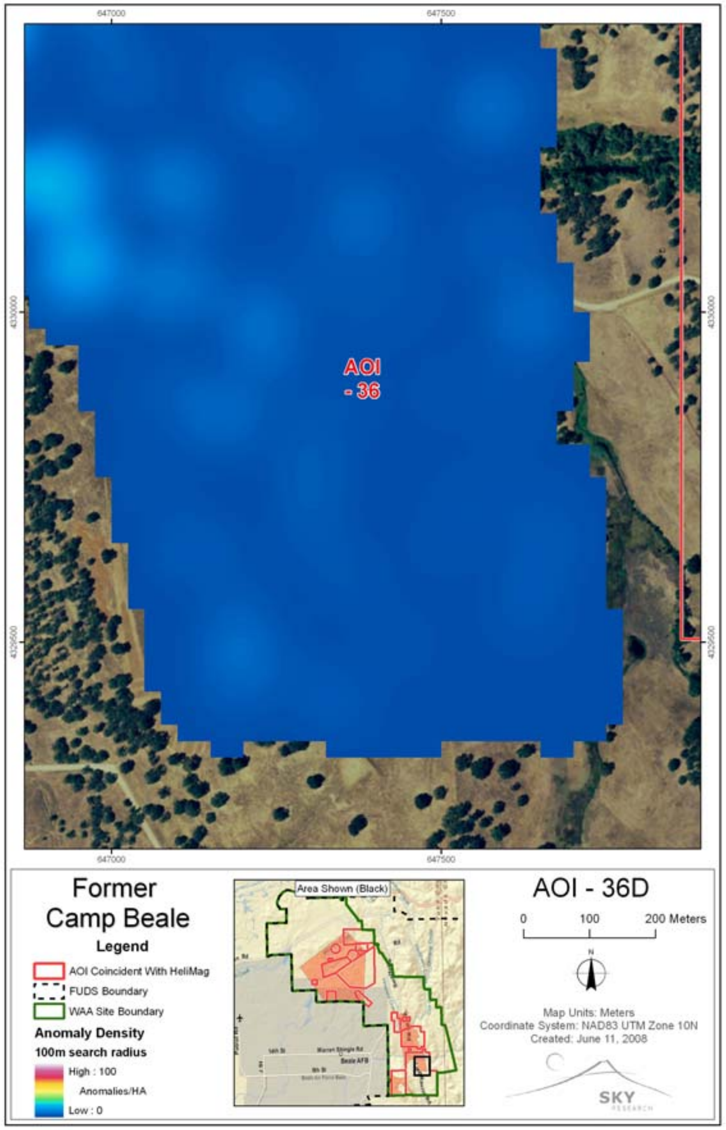

647000
647500
4330500
4330000
AOI
- 36
Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 36B
0
100
200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

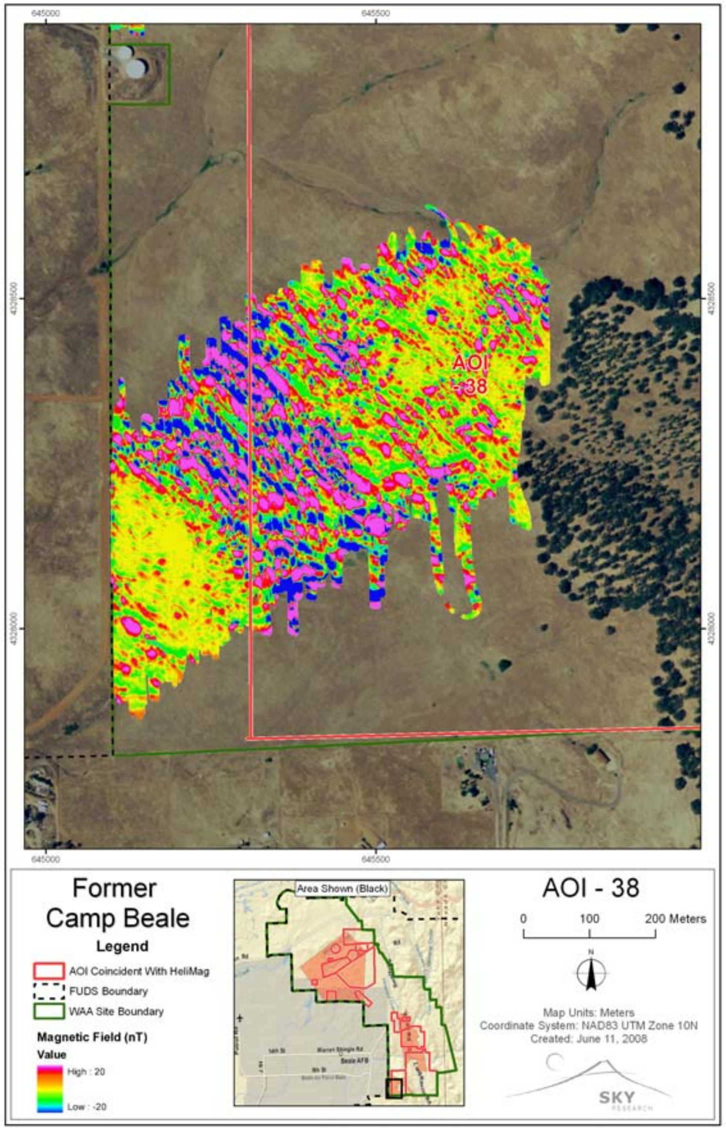

647000
647500
4330500
4330000
AOI
- 36
Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 36B
0
100
200 Meters
N
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

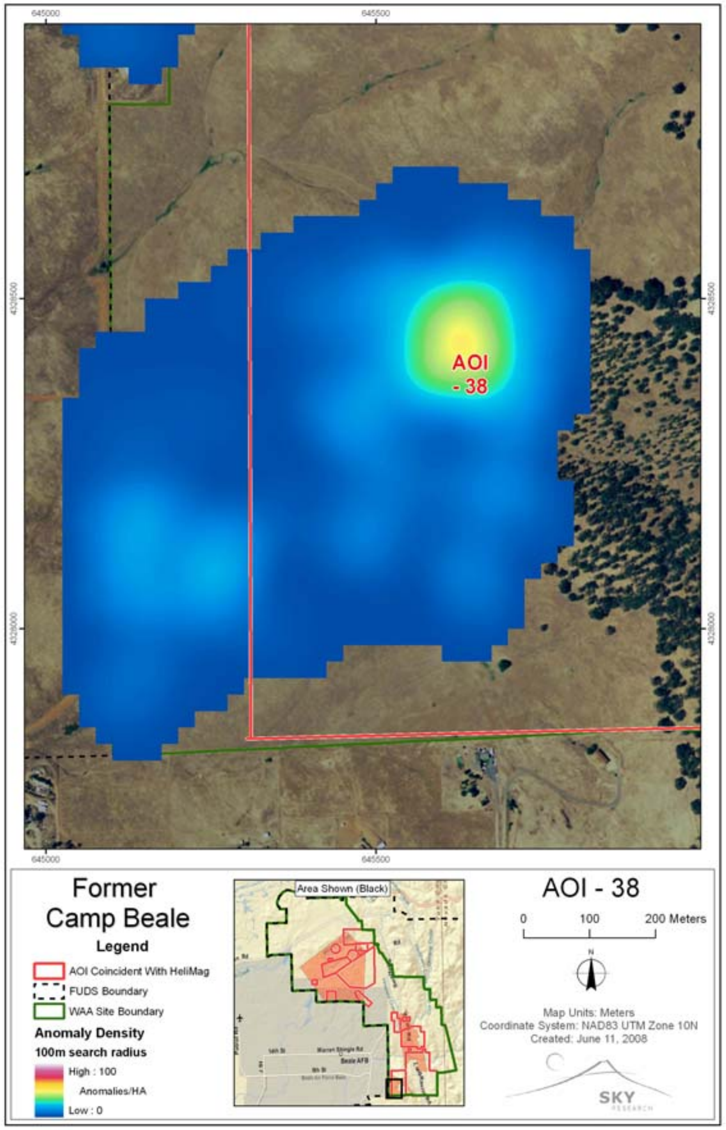

AOI - 36
AOI - 38
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 36C
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY


AOI - 36
AOI - 38
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 36C
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

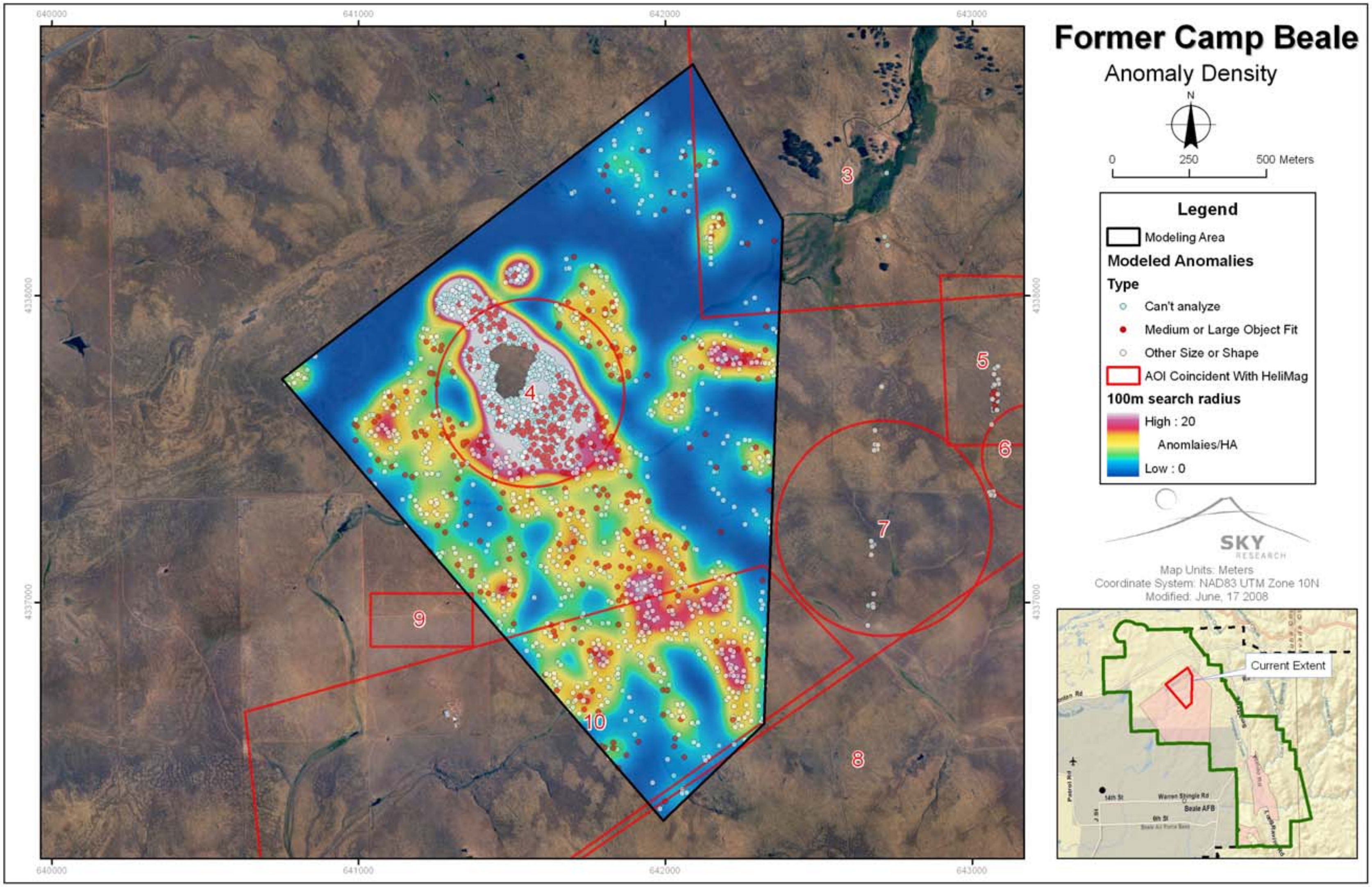

AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
Area Shown (Black)
AOI - 36D
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

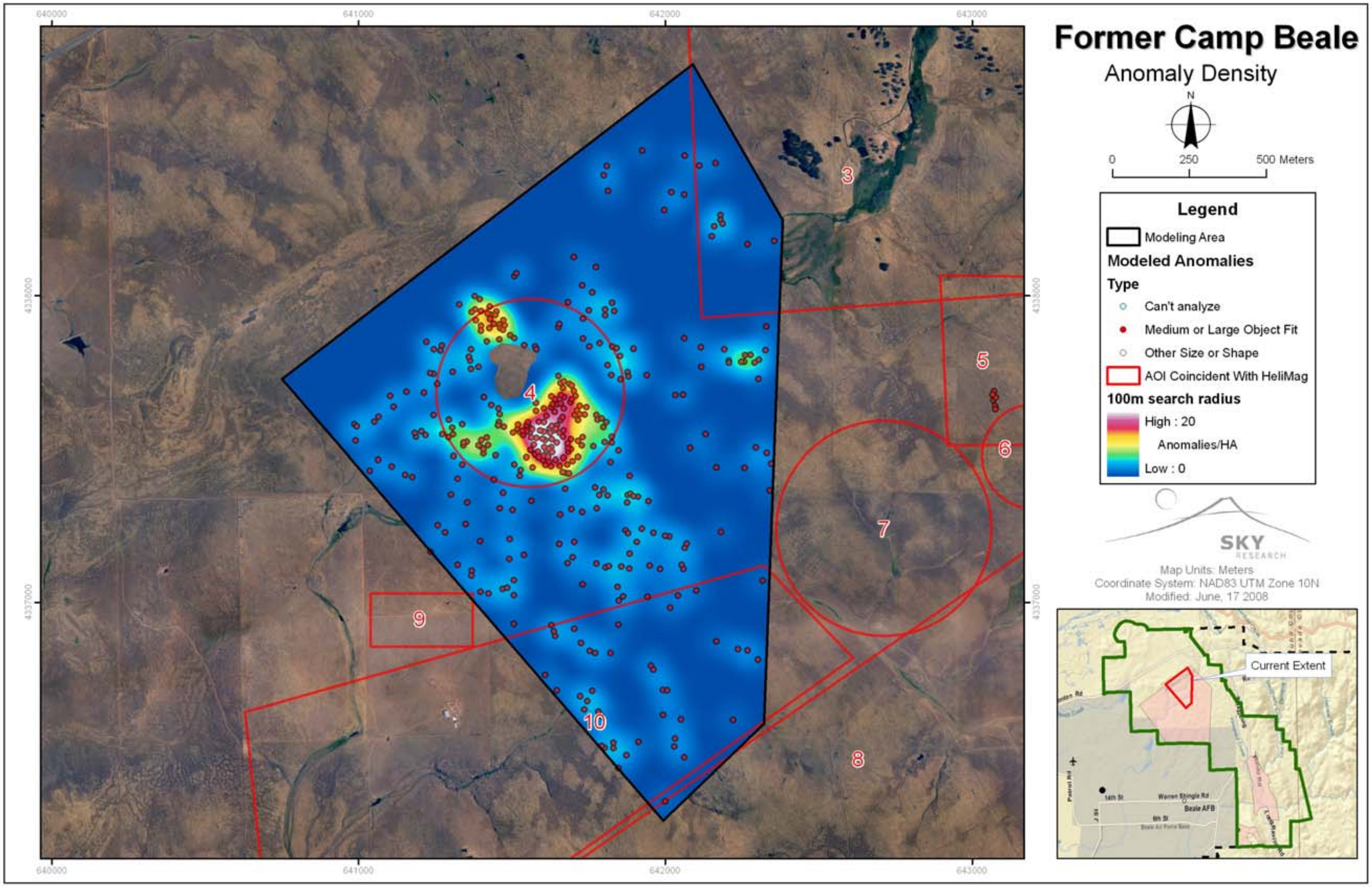

AOI - 36
Former Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
Area Shown (Black)
AOI - 36D
0
100
200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
SKY

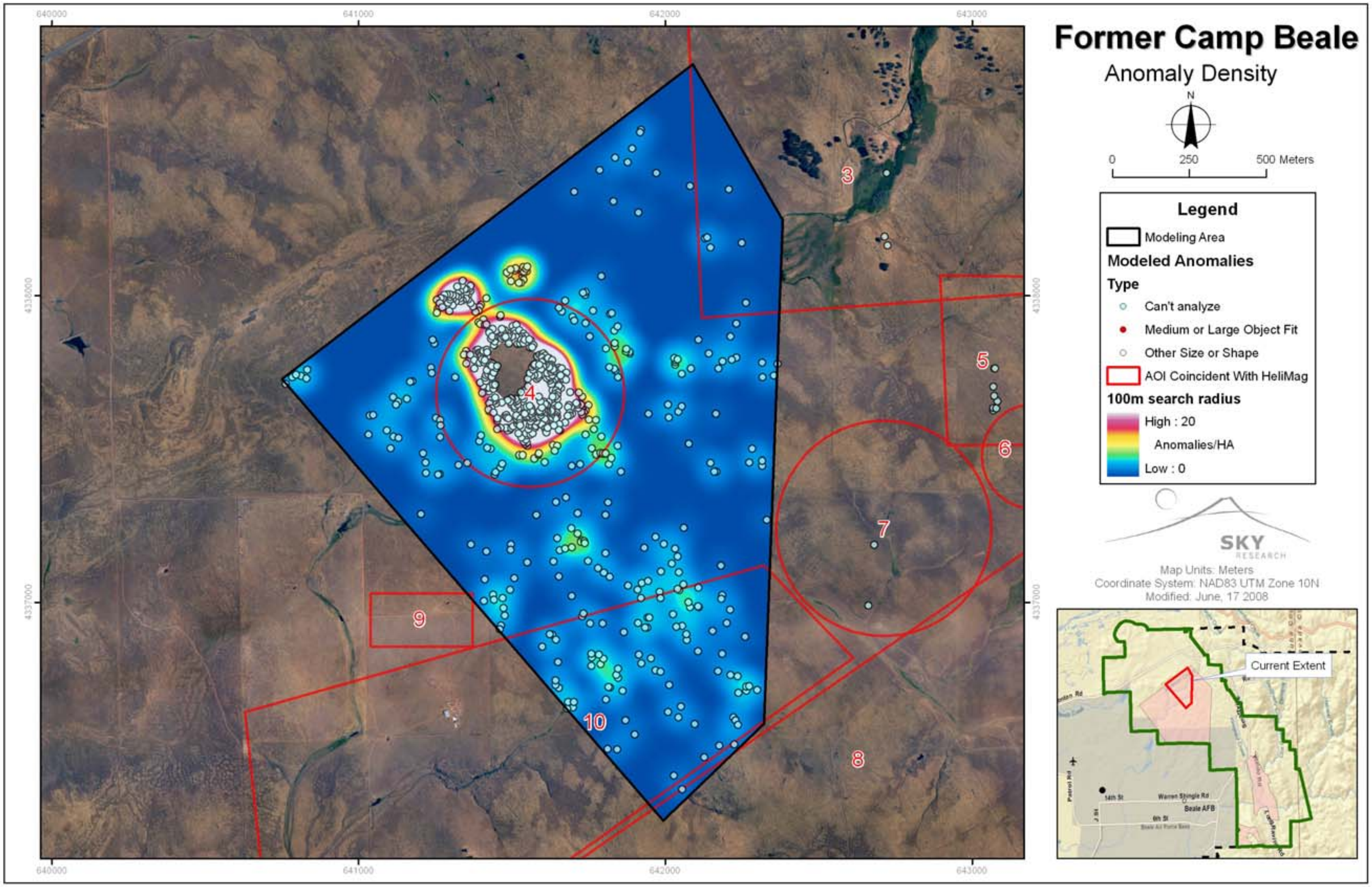

Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Magnetic Field (nT)
Value
High : 20
Low : -20
AOI - 38
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
Area Shown (Black)
AOI - 38
SKY

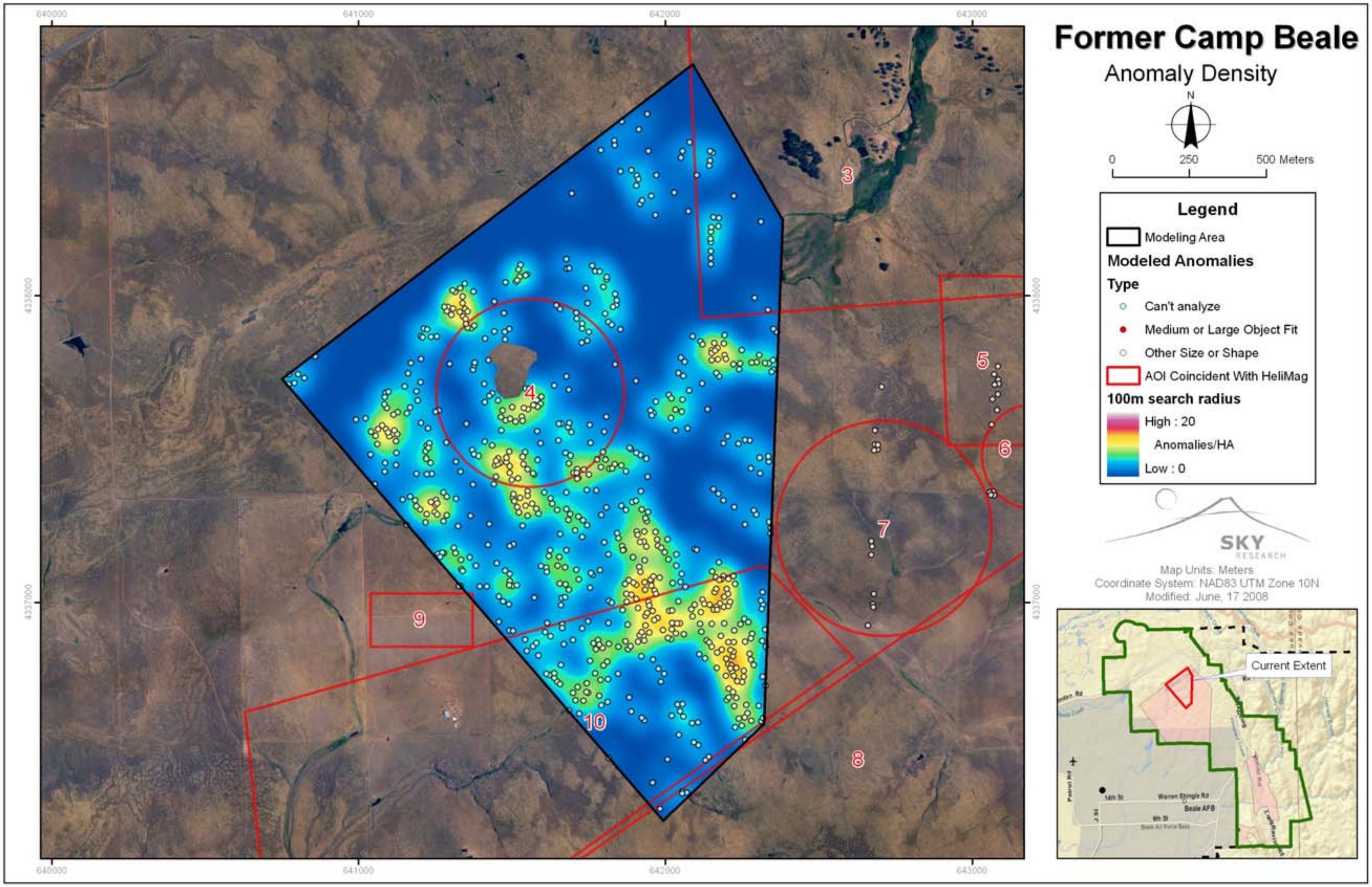

Former
Camp Beale
Legend
AOI Coincident With HeliMag
FUDS Boundary
WAA Site Boundary
Anomaly Density
100m search radius
High : 100
Anomalies/HA
Low : 0
AOI - 38
0 100 200 Meters
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Created: June 11, 2008
Area Shown (Black)
AOI - 38
SKY

APPENDIX B –ANOMALY DENSITY RESULTS IN NORTHERN SUBSET AREA


Former Camp Beale
Anomaly Density
N
0
250
500 Meters
Legend
Modeling Area
Modeled Anomalies
Type
Can't analyze
Medium or Large Object Fit
Other Size or Shape
AOI Coincident With HeliMag
100m search radius
High : 20
Anomlaies/HA
Low : 0
SKY
RESEARCH
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Modified: June, 17 2008
Current Extent
3
4
5
6
7
8
9
10


Former Camp Beale
Anomaly Density
N
0
250
500 Meters
Legend
Modeling Area
Modeled Anomalies
Type
Can't analyze
Medium or Large Object Fit
Other Size or Shape
AOI Coincident With HeliMag
100m search radius
High : 20
Anomalies/HA
Low : 0
SKY
RESEARCH
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Modified: June, 17 2008
Current Extent
3
4
5
6
7
8
9
10
640000
641000
642000
643000
4338000
4337000


Former Camp Beale
Anomaly Density
N
0
250
500 Meters
Legend
Modeling Area
Modeled Anomalies
Type
Can't analyze
Medium or Large Object Fit
Other Size or Shape
AOI Coincident With HeliMag
100m search radius
High : 20
Anomalies/HA
Low : 0
SKY RESEARCH
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Modified: June, 17 2008
Current Extent
640000
641000
642000
643000
4338000
4337000
3
4
5
6
7
8
9
10


Former Camp Beale
Anomaly Density
N
0
250
500 Meters
Legend
Modeling Area
Modeled Anomalies
Type
Can't analyze
Medium or Large Object Fit
Other Size or Shape
AOI Coincident With HeliMag
100m search radius
High : 20
Anomalies/HA
Low : 0
SKY
RESEARCH
Map Units: Meters
Coordinate System: NAD83 UTM Zone 10N
Modified: June, 17 2008
Current Extent
3
4
5
6
7
8
9
10
640000
641000
642000
643000